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1. Executive Summary

The Clean Fuels Market Assessment is an essential element of the California Fuel Infrastructure Development Plan. The Assessment provides a foundation of logic to the Plan by assessing California's most immediate clean fuel infrastructure needs for transportation applications and providing essential program recommendations on how to meet those needs. An immediate focus is to help guide the Plan's infrastructure expenditures of the currently available $6 million, such that the potential to displace petroleum fuels (gasoline and diesel) will be maximized. This inaugural version of the Assessment is designed to provide a dynamic process whereby annual reviews and updates can be used by the Energy Commission to set infrastructure goals and development priorities, assist in the preparation of legislative or administrative remedies, and help guide budget appropriations.

The Plan targets expansion of fueling infrastructure for alternative-fuel vehicles and applications that will displace the greatest volumes of petroleum based fuels. Whenever possible, achieving quantifiable air-quality benefits is also an important objective. In addition to mainstream alternative fuels, a variety of "unconventional" liquid fuels (e.g., biodiesel, Fischer-Tropsch diesel) can potentially help California meet both objectives. Although their immediate infrastructure needs in California may be minimal or require further definition, such fuels should remain candidates for future allocations under the Energy Commission's Clean Fuel Infrastructure Development Plan. Moreover, assistance for these fuels beyond infrastructure development (e.g., policy support) appears to be warranted, given the substantial potential benefits at minimal budget impact to the State.

For the purposes of expending the Plan's currently available $6 million for infrastructure development, candidate fuels assessed in this report include natural gas, propane, ethanol, methanol, electricity and hydrogen. Recommendations for immediate funding allocations are provided for certain fuels and applications; for others, monitoring of progress and/or further assessments are suggested.

Since mid 2000, California has been experiencing an ongoing, major energy crisis. Virtually all transportation fuel markets have been affected, and new developments are occurring on a daily basis. A major concern is the rising demand for natural gas by electricity generators, which may severely constrain available natural gas supplies for the transportation sector, and may also further affect supply and price for other key fuels (e.g., propane). Based on the best available information as of early 2001, it appears that supply and/or distribution problems for alternative fuels such as natural gas and propane will persist in the short term, perpetuating volatile prices that are higher than conventional fuels on an energy-equivalent basis. Longer-term supply, demand and pricing scenarios suggest there will be a return to more competitive levels within two to four years.

The recommendations in this report are based on the assumption that, over the longer run, further investments to diversify fuels in the transportation sector will help alleviate (rather than exacerbate) California's current energy crisis. The $6 million that is immediately available for

2001 allocations under the Plan is a relatively small amount, compared to the magnitude of infrastructure investments needed. Using the best-available information, these recommendations are focused on the most promising infrastructure deployments that 1) are most in need of government funds to become commercially self-sustaining, and 2) appear to entail the lowest risk to become stranded investments.

Currently, the heavy-duty vehicle (HDV) sector offers the best opportunities to displace consumption of petroleum fuels and achieve air quality benefits. However, the emissions competitiveness of diesel-fueled HDVs is likely to rapidly improve over the next five years. As such, it's difficult to predict the longer-term degree to which emissions-related regulations will continue to drive AFV commercialization. This makes it even more important to immediately build momentum towards self-sustainable commercial AFV markets -- while energy security drivers are complemented by air quality regulations and related incentives. Fleet applications that make the best candidates for high-priority resource allocations in the "large" and "medium" project categories (>$250,000 and up to $250,000, respectively), include refuse haulers, transit buses, class 8 trucks (return to base), high-fuel use LDV applications (e.g., large taxicab fleets), and high-fuel-use MDV applications such as airport shuttle buses and package-delivery services. There are also potential AFV applications that may not currently involve high fuel use, but are capable of significantly advancing California's long-term potential to displace petroleum fuels. Such applications are good candidates for resource allocations in the "small to medium" category (roughly $65,000 to $250,000 per project). These include school buses and small light-and medium-duty fleets seeking "startup" operations with dedicated AFVs utilizing a single dispenser, or multiple vehicle refueling appliances (VRAs).

The task to establish sufficient numbers of AFV fueling stations is significant. In the heavy-duty sector alone, tens of thousands of AFVs will potentially be deployed in California over the next decade, either to meet various government regulations or exploit incentive programs. In the greater Los Angeles area, five new fleet rules from the South Coast Air Quality Management District's 1190 Series could potentially deploy more than 16,000 heavy-duty AFVs over the next 15 years. In other parts of California, the California Air Resources Board's newly adopted transit bus fleet rule is already stimulating increased deployments of alternatively fueled transit buses at an estimated 14 transit districts, including large districts in Sacramento, San Diego, and the Bay area.

Specific findings and recommendations by vehicle type, application and topic are as follows:

1.1 Natural Gas Vehicles and Infrastructure

Natural gas is currently the leading alternative fuel in California, in terms of commercially available low-emission vehicles and numbers of fueling stations specifically for automotive applications. New deployments are already underway in response to the above-noted regulations, and it appears that most of the demand for heavy-duty AFVs will be met by natural gas vehicles fueled by CNG and LNG. For LNG alone, it's possible that as many as 6,000 new HDVs and 44 new fueling stations will be deployed by 2010 in the western United States, if industry objectives can be met. Corresponding vehicle and infrastructure investments will cost an estimated $167 million at the low end, and as much as $334 million.

Approximately $9 to $12 million per year will be needed from grants and incentive programs, to augment industry's share (roughly 75%). Large investments in fueling infrastructure are also needed if greater numbers of CNG vehicles are to be deployed, including a significant portion of funding towards so-called "L/CNG" stations that dispense both LNG and CNG.

Also, in response to the energy crisis, California will need to be more proactive in developing new means of production for alternative transportation fuels. New actions are needed to reduce its ~85% dependency on imported natural gas, currently transported in by pipeline deliveries or LNG shipments that appear fully subscribed. Potential strategies to augment California's supply of clean transportation fuels include further exploiting its large untapped resources of waste-to-energy technologies, and using emerging gas-to-liquids technology to extract stranded reserves of associated natural gas, which can yield LNG, zero-sulfur synthetic diesel fuel, and methanol (among other useful products). These activities are needed in addition to existing efforts to develop small-scale liquefaction plants to produce LNG, using pipeline gas or remote gas sources.

To help meet all these needs, the following recommendations are made for the natural gas fueling infrastructure under the currently available $6 million:

- Approximately $2.4 million is recommended to cost-share new LNG stations, for use by refuse hauler fleets, return-to-base delivery fleets, and transit districts.

- Approximately $1.0 million is recommended to cost-share new L/CNG stations, or add the L/CNG station feature to conventional LNG stations. These stations can be used by fleets seeking an integrated strategy to natural gas vehicles, i.e., fueling of light-, medium-, and heavy-duty vehicles at the same station.

- Approximately $700,000 to $900,000 is recommended to cost-share new CNG stations for use by school districts, high-fuel-use medium-duty fleets such as taxicabs, and small fleets using vehicle refueling appliances.

- Approximately $1.2 million is recommended to cost-share new gas-to-liquid technologies that can produce LNG or other useful transportation fuels.

1.2 Propane Vehicles and Fueling Infrastructure

Propane vehicles have potential to significantly displace petroleum fuels and provide air quality benefits in California. Recent price volatility and supply issues remain a concern in the propane industry, although this has been the case with many transportation fuels. It is difficult to estimate the exact potential of propane-fueled vehicles to displace gasoline and diesel due to the current limited offerings of dedicated propane vehicles, and the lack of any significant fuel-use requirements affecting bi-fuel vehicles. Significant numbers of bi-fuel vehicles are currently being operated by California fleets. This includes approximately 700 Ford F-150 pickups operated primarily on gasoline by Caltrans, which is reportedly willing and able to make the switch to propane. As a modest start to expanding the propane fueling infrastructure and possibly stimulating greater deployments of dedicated vehicles, it is recommended that $500,000 to $700,00 be allocated to cost share new automotive-style propane stations in California.

1.3 Electric Vehicles (EVs) and Recharging Infrastructure

With recent changes adopted in the California Zero-Emission Vehicle (ZEV) program, it appears that the total number of battery EVs deployed in 2003 will vary from 4,450 to 15,450. This range in part reflects uncertainty about how the modified ZEV program will alter the relative market shares of conventionally fueled light-duty vehicles versus battery-electric vehicles and other clean-fuel technologies.

The ramifications of California's current power crisis to EV commercialization are not clear, and the potential range of EV numbers that will be deployed is broad. It is recommended that further assessments are conducted before further consideration is given to funding EV infrastructure development under Plan funding. Specific topics for assessment are as follows:

- Projected numbers and types of EVs that will be deployed in California for the 2003 to 2010 timeframe, by type and end use (government fleets, private users, utilities, etc.)
- Existing EV stations by location, type and how they are used by end users (fleets as well as private individuals)
- Relationships between the density of fast chargers and public charging stations
- Impacts of neighborhood electric vehicles (NEVs) on EV infrastructure needs (residential and public stations)
- Feasibility to adopt statewide ordinances that require construction of new homes and businesses to be compatible with state-of-the-art EV charging systems
- Potential to develop and deploy an effective and affordable billing system for public EV charging stations
- Progress of hybrid electric vehicle (HEV) technology and special infrastructure requirements, if any, that may emerge

1.4 Ethanol Vehicles and Fueling Infrastructure

FFVs with capability to operate on ethanol (E85) or gasoline are widely available in California, but currently there are no E85 fueling stations. Nationally, demand for E85 will grow significantly over the next 20 years, but there are no known plans to sell meaningful volumes in California. Beginning in 2003, ethanol will replace MTBE as the oxygenate in California gasoline, resulting in a major increase in ethanol demand. This will further cloud the future of E85 in California, because the use of ethanol for FFVs is not currently economically competitive with its use as an oxygenate for reformulated gasoline. It is recommended that no 2001 funds are allocated to ethanol infrastructure under the California Clean Fuels Infrastructure Development Plan, although future market assessments should revisit this as a possible use of funds.

1.5 Methanol Vehicles and Fueling Infrastructure

Methanol is an excellent carrier of hydrogen for use in fuel cells, and can also work well in vehicles with internal combustion engines. Currently, no major vehicle manufacturers are selling on-road vehicles that use methanol fuel, but this situation may change since several major auto manufacturers have announced plans to sell methanol-fueled fuel cell vehicles by 2004. Members of the California Fuel Cell Partnership are exploring possible scenarios for developing a methanol fuel distribution system for fuel cell vehicles, and assessing commercialization issues. Methanol infrastructure should remain a candidate for potential support under the California Clean Fuels Infrastructure Development Program, but no funding allocations are recommended under the currently available funding.

1.6 Hydrogen Vehicles and Fueling Infrastructure

Hydrogen is expected to be the long-term fuel for fuel cell vehicles. Achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production and infrastructure investments of very large proportions. Activities under the California Fuel Cell Partnership and the federal hydrogen program are addressing some of these issues. Hydrogen infrastructure should remain a primary candidate for future support under the California Clean Fuels Infrastructure Development Plan. However, it is premature to allocate Plan funds to hydrogen infrastructure.

1.7 Recommendations for AFV Infrastructure Incentives

An important ongoing need in advancing the commercial viability of clean fuel technologies is to implement effective, affordable and workable incentives. Many types of incentives have been used in California and other states to support AFV deployment, but some have clearly been more effective than others. Generally, state and local grants have provided the best motivation for fleets to purchase AFVs, whereas tax credits have worked well for individual AFV owners. In some cases, well-meaning but poorly designed and implemented incentive programs have resulted in ineffective use of funds or even financial disaster (e.g., the Arizona program). Greater understanding is needed on the mechanics of effective incentives for AFVs and fueling stations. It is recommended that the Energy Commission and its partners conduct a detailed assessment of financial and administrative incentives that can most effectively help deploy AFVs with maximum displacement of petroleum fuels.

2. Background and Introduction

2.1 The California Clean Fuel Infrastructure Development Plan

Overall, about 50 percent of California's energy consumption results from transporting goods and people. With 34 million people and more than 24 million registered motor vehicles, California is the world's second largest consumer of gasoline and diesel fuel, exceeded only by the remainder of the United States. More than 99 percent of the state's transportation energy is derived from petroleum fuels. Statewide, there are approximately 9,500 retail fueling stations that dispense gasoline and diesel fuel. Each year, a total of 13.5 billion gallons of gasoline and 4.4 billion gallons of diesel are dispensed at those stations.[1] On average, each station dispenses about 5,000 gallons of petroleum fuel each day.

For several decades, the Energy Commission has worked with the California Air Resources Board and other California public agencies to diversify the transportation fuels market by helping to develop a market for vehicles that use cleaner burning alternative fuels. An essential element of these efforts has been parallel development of the necessary fueling infrastructures to support such vehicles.

The California Clean Fuel Infrastructure Development Plan (Plan) is an annual resource and planning tool of the Energy Commission for the integrated development of clean fuels infrastructure in California. This Plan allows the Energy Commission to track and promote competitive, non-petroleum energy alternatives throughout California, and oversee infrastructure development through project funding and incentives. In targeting expansion of the clean fuels infrastructure, the Plan addresses numerous alternative fuels and vehicle technologies, and allocates $6 million in currently available funds to support infrastructure development. Table 1 provides an overview of the Plan. Table 2 provides examples of clean fuel stations that are candidates for further development under the Plan, along with the corresponding vehicle types and technologies, and the anticipated timeframe for development activities.

[1] California Energy Commission, various documents from website (http://www.energy.ca.gov/).

Table 1. Overview of the California Fuel Infrastructure Development Plan

Duration	♦ Multi-year, beginning Fiscal Year 2000-2001
Current Funding	♦ $6 million in Petroleum Violation Escrow Account (PVEA) funds ♦ Approximately 4:1 cost sharing from other sources
Major Objectives	♦ Assess existing Alternative Fuel infrastructure ♦ Assess current and potential markets and technologies to set development goals, ♦ Create economic market for vehicle, market projection ♦ Coordinate infrastructure development, ♦ Determine effective financial and administrative incentives to achieve goals ♦ Establish evaluative framework to measure and determine the success in attaining annual market development goals ♦ Provide an annual review and planning mechanism to guide future state investment and encourage private investment
Year 1: Focus and Key Deliverables	♦ Clean Fuels Market Assessment ♦ Master plan to guide public and private investments in non-petroleum fueling infrastructure ♦ Broad-based and targeted clean fuel infrastructure solicitations
Subsequent Years: Focus and Key Deliverables	♦ Continuously updated mechanism to determine and implement infrastructure development priorities ♦ Continued updates and renewed guidelines for investment of state funds in the clean fuel infrastructure
Sources of Cost Sharing for Infrastructure Development	♦ Federal agencies (e.g., DOE) ♦ Other State agencies (e.g., CARB) ♦ Local agencies (AQMDs and APCDs) ♦ Private industry
Plan Participants, Stakeholders, and Sources of Input	♦ Technical Advisory Group (see table below) ♦ Commission staff ♦ Consultants ♦ Academic community ♦ General public ♦ Associations

Table 2. Examples of candidate clean fuels and vehicle technologies

Type of Clean Fuel Station	Existing or Potential Users (Vehicles / Technologies)	Anticipated Timeframe
Compressed Natural Gas (CNG)	♦ Internal Combustion Engine Vehicles ♦ Hybrid Electric Vehicles	♦ Near term ♦ Near term
Liquefied Natural Gas (LNG)	♦ Internal Combustion Engine Vehicles ♦ Hybrid Electric Vehicles	♦ Near term ♦ Longer term
L/CNG (capable of supplying both LNG and CNG)	♦ Internal Combustion Engine Vehicles ♦ Hybrid Electric Vehicles	♦ Near term ♦ Near term
Liquefied Petroleum Gas (Propane)	♦ Internal Combustion Engine Vehicles ♦ Hybrid Electric Vehicles	♦ Near term ♦ Near term
Electric Charging	♦ Battery Electric Vehicles ♦ “Plug-In” Hybrid Electric Vehicles	♦ Near term ♦ Longer term
Ethanol	♦ Flexible Fuel Vehicles ♦ Hybrid Electric Vehicles	♦ Near term ♦ Longer term

	♦ Fuel Cell Vehicles (Reformer)	♦ Longer term
Methanol	♦ Internal Combustion Engine Vehicles ♦ Hybrid Electric Vehicles ♦ Fuel Cell Vehicles (Reformer) ♦ Fuel Cell Vehicles (Direct Methanol)	♦ Near/Longer ♦ Longer term ♦ Longer term ♦ Longer Term
Hydrogen	♦ Internal Combustion Engine Vehicles ♦ Fuel Cell Vehicles (Direct Hydrogen)	♦ Longer term ♦ Longer term

In addition to these mainstream alternative fuels, a variety of "unconventional" liquid fuels can potentially help displace petroleum fuels in California, while simultaneously providing significant air quality benefits. These include bio-diesel, Fischer-Tropsch diesel, and Pure Energy's P-Series fuel. Such fuels hold clear promise to further diversify the fuel mix in California's transportation sector. Although their immediate infrastructure needs in California may be minimal or require further definition,[2] such fuels should remain candidates for future allocations under the Energy Commission's Clean Fuel Infrastructure Development Plan. Moreover, assistance for these fuels beyond infrastructure development (e.g., policy support) appears to be warranted, given the substantial potential benefits at minimal budget impact to the State.

For the purposes of expending the currently available $6 million on infrastructure development, this assessment focuses on the following "conventional" alternative transportation fuels: natural gas, propane, ethanol, methanol, electricity and hydrogen. These fuels require challenging and immediate modifications to the existing fueling infrastructure before greater commercial deployment can occur.

2.2 Technical Advisory Group

To assist the Energy Commission in developing and implementing the Plan, a Technical Advisory Group (TAG) was formed in mid 2000. As

Table 3 shows, there are five primary types of stakeholders represented on the TAG, with many different individual organizations contributing a wide range of expertise.

Table 3. Stakeholder organizations represented on the Technical Advisory Group

[2] For example, Energy Commission staff have made preliminary estimates about the costs of modifying an existing diesel terminal for Fischer-Tropsch diesel.

Stakeholder Type	Name of Organization / Agency Represented on the TAG	Primary Area of Specific Expertise and / or Contribution
Private Sector Fleets and End Users	♦ Sunline Transit District ♦ Los Angeles County Transit Authority ♦ Jack B. Kelley, Inc ♦ California Fleet	♦ Transit Buses ♦ Transit Buses ♦ HD Trucks ♦ End User
Utilities, Fuel Suppliers and Infrastructure Industry	♦ Methanex Corporation ♦ Trillium USA ♦ Pacific Gas & Electric ♦ The Gas Company / Sempra Energy ♦ Pinnacle CNG Systems LLC ♦ Pickens Fuel Corporation ♦ FleetStar / Applied LNG Technologies ♦ Parallel Products ♦ Delta Liquid Energy	♦ Methanol Supplier ♦ CNG Turnkey Provider ♦ CNG / LNG Utility ♦ CNG Utility ♦ CNG Turnkey Provider ♦ CNG / LNG Turnkey Provider ♦ CNG, LNG, L/CNG Supplier ♦ Ethanol / E85 ♦ LPG / Propane Supplier
Government Agencies	♦ California State Department of Education ♦ California Department of General Services ♦ San Joaquin Valley APCD ♦ California Air Resources Board ♦ South Coast AQMD ♦ California Department of Transportation ♦ California Department of Fish & Game ♦ California Department of Parks and Rec.	♦ AFV User ♦ AFV User ♦ Incentives, Technology ♦ Incentives, Regulations ♦ Incentives, Regulations ♦ AFV User, Traffic mitigation ♦ AFV User ♦ AFV User
Trade Associations, Consultants, Research Institutes and National Laboratories	♦ California Natural Gas Vehicle Coalition ♦ Gas Technology Institute ♦ California Electric Transportation Coalition ♦ Argonne National Laboratory ♦ DOE Clean Cities ♦ Gladstein & Associates	♦ NGVs and Infrastructure ♦ NGVs and Infrastructure ♦ EVs and Infrastructure ♦ Various AFV Technologies ♦ Infrastructure Coalitions ♦ ICTC and LNG Consultant
Vehicle and Engine Manufacturers	♦ Ford Motor Company ♦ American Honda Motor Company ♦ Toyota Motor Sales ♦ Cummins Engine Company ♦ Daimler-Chrysler Corporation ♦ General Motors	♦ AFVs and Infrastructure ♦ AFVs and Infrastructure ♦ AFVs and Infrastructure ♦ Heavy-Duty AFV Engines ♦ AFVs and Infrastructure ♦ AFVs and Infrastructure

2.3 Overview of the Clean Fuels Market Assessment

The Clean Fuels Market Assessment is a foundation and essential element of the California Fuel Infrastructure Development Plan. The objective of this Assessment is to assist the Plan in accomplishing the following:

- Identify and analyze barriers and impediments to expanding the alternative fuels infrastructure in California
- Set realistic and practical development goals for infrastructure
- Help develop effective financial and administrative incentives
- Assist in the preparation of legislative or administrative remedies
- Conduct public outreach to stimulate private participation and investment
- Serve as an adjunct to the annual Program Workplan process
- Assist in the selection of infrastructure-development activities for funding
- Assist to develop priorities and plan activities
- Conduct public advertising and information
- Identify fuel-specific issues (supply/price)

This inaugural version of the Clean Fuels Market Assessment focuses on assessing the market potentials for various types of clean fuels in California. In subsequent years, this Market Assessment will be updated and used as an ongoing tool to set new annual goals and development priorities, assist in the preparation of legislative or administrative remedies, and help guide budget appropriations.

2.4 Scope, Information Sources and Limitations

Key California-specific components identified in this Assessment include:

- Existing infrastructure and vehicle base, by fuel type
- Time horizon for technological maturity
- Fuel-specific considerations (e.g., vehicle performance, range, cost, fuel supply, public access, card reader access)
- Building codes and standards
- Existing and potential funding sources and mechanisms
- Existing and potential incentives (financial and administrative)

A wide variety of data and information were gathered from many sources in preparing this report and developing this Clean Fuels Market Assessment. A primary source was survey input received from TAG members of three main groups: 1) the alternative-fuel supply and infrastructure industry, 2) engine and vehicle manufacturers, and 3) vehicle end users. In addition, to augment the input received from the TAG through these surveys, extensive input was obtained from Energy Commission staff and various organized groups with similar objectives to those of the Clean Fuel Market Assessment. These include the Infrastructure Working Group of the Gas Technology Institute, the California Fuel Cell Partnership, and others.

Using information obtained from these various sources, this Market Assessment provides guidance towards expanded use of the clean fuel infrastructure in California to assist in displacement of petroleum fuels. The following caveats and limitations are noted:

- Since mid 2000, California has been experiencing an ongoing, major energy crisis. Virtually all transportation fuel markets have been affected, and new developments are occurring on almost a daily basis such as delivery backlogs on new natural gas storage, dispensing and piping equipment. However, a major concern is the rising demand for natural gas by electricity generators, which may severely constrain available natural gas supplies for the transportation sector, and may also further affect supply and price for other key fuels (e.g., propane). This report attempts to assess likely ways in which the energy crisis may impact potential AFV infrastructure projects, but comprehensive analysis is not within its scope. The recommendations provided in this report are based on the assumption that, over the longer run, further investments to diversify fuels in the transportation sector will help alleviate (rather than exacerbate) California's current energy crisis.

- Not all TAG members responded to the survey or follow-up telephone calls. For all information that was received, reasonable attempts were made to corroborate the input and clarify or expand where important. However, rigorous verification of the information provided is beyond the scope of this study.

- On-road applications for clean fuels are highlighted in this report; however, many off-road vehicles (e.g., construction, military, airport, marine) use the same alternative-fuel engines that are described in this report. Therefore, much of the findings and conclusions of this study can be extrapolated to off-road vehicle sectors.

2.5 Major Drivers for Use of Clean Fuels

Three main categories of on-road vehicles consume the vast majority of gasoline and diesel fuel in California: light-duty vehicles (LDVs), medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs). Generally, LDVs and MDVs are powered by gasoline engines, and HDVs are powered by diesel engines. Effectively, today there are no significant energy-related regulations that drive the use of alternative fuels in these vehicle sectors, although some regulations (e.g., the Energy Policy Act and Corporate Average Fuel Economy standards) have helped deploy vehicles capable of using non-petroleum fuels. Historically, it has been California's air pollution control laws that have been the major regulatory driver towards dedicated, optimized alternative fuel vehicles.

Currently, the commercial viability of specific clean fuels and technologies continues to depend partially on their ability to provide emissions reductions. In California, LDVs, MDVs and HDVs each contribute significantly to the overall emissions inventory, and are being aggressively targeted for further emissions reductions. However, there are significant differences among these categories in the magnitude of emissions reductions that are likely to result from alternative fuels. Because the emissions competitiveness of conventionally fueled vehicles continues to improve, over the longer term it's unclear to what degree air quality regulations can continue to be a major driver towards deployment of AFVs.

Appendix A: on page 110 provides a detailed discussion on the emissions competitiveness of AFVs versus diesel and gasoline vehicles. It focuses on the HDV sector, where currently the largest emissions reductions can be realized using alternative fuels, yet strong competition to meet new emissions standards is on the horizon from advanced diesel technologies. By 2007, both diesel and alternative-fuel heavy-duty engines will need to emit about 90% less NOx and PM than today's cleanest alternative fuel engines. This will be challenging for both advanced diesel and alternative fuel engines, but it is noteworthy that diesel engines have significantly "farther to go" to reach the target levels. Manufacturers that take an alternative fuel approach may have significant engineering and cost advantages, at least for certain engines and applications.

Beyond emissions considerations, certain types of HDVs are conducive to using alternative fuel for the following reasons:

- Up to 70% of the operating costs of HDVs are attributable to purchasing fuel; this makes the economics of using clean fuels more attractive (historically, at least, natural gas has been cheaper than petroleum fuels).

- Most HDVs are centrally fueled at large yards by professionally trained fueling and maintenance personnel; this can help defray the higher costs associated with using and maintaining alternative fuel vehicles and fueling stations.

- Large HDV "anchor" fleets can provide the minimum fuel throughput levels needed to make alternative fuel stations economically attractive to entrepreneurs and venture capitalists.

For all the reasons discussed above, HDVs are currently the most attractive vehicle sector to target for displacement of petroleum fuel and emissions reductions using alternative-fuel engines. Specific vehicle types that are well suited include transit buses, return-to-base delivery trucks, and refuse haulers. Expanded deployment of clean fuel technologies in these applications (as well as others) largely depends on continued progress with infrastructure development. High-fuel-use HDV applications offer the best focal point for such development activities. However, there are also certain LDV and MDV applications (e.g., taxicabs and shuttle buses with high fuel use) that also make good candidates for expanded use of alternative fuels. Detailed findings and recommendations are discussed further in subsequent sections of this report.

2.6 Avoidance of "Stranded" Investments, and Criteria for "Exit" Strategies

One legitimate concern when allocating public funds towards deployment of alternative fuel infrastructure is the possibility of "stranded investments." For the purposes of the Energy Commission's alternative fuel infrastructure program, stranded investments might be considered allocations that ultimately do not significantly displace gasoline or diesel consumption. Examples of scenarios in which today's infrastructure investments could become stranded include the following:

- A particular alternative fuel becomes cost prohibitive, or its supply can't meet demand, leading to severe under-utilization of newly constructed fueling stations

- Vehicle and/or engine manufacturers fail to sell, manufacture or market sufficient numbers of an AFV type, or they unexpectedly phase out existing products

- End users refrain from purchasing today's AFVs in hopes of obtaining longer-term, more advanced technology at a later date

- Miscellaneous unforeseen circumstances occur (e.g., health & safety problems with a fuel or technology)

- Technological breakthroughs with conventionally fueled vehicles or competing AFV types render another AFV type unable to compete

As one example, consider the AFV infrastructure investments currently being made in natural gas fueling facilities. Some parties have claimed that large investments of this type for transit buses (in response to CARB's transit bus rule or SCAQMD's Rule 1992) could become stranded when transit districts are required to begin procuring zero-emission buses in the 2008 to 2010 time frame. CARB considered this issue in adopting its transit rule, but concluded that the purchase of natural gas buses will have "strong viability" at least until model year 2015. CARB staff also noted that "the existing natural gas infrastructure will be transferable to the operation of fuel cell buses and could substantially reduce the infrastructure cost for fuel cell bus fleets."[3] This is because reforming of natural gas at transit districts will be one option to obtain hydrogen for fuel cell buses. Also, technologies used to compress natural gas and store it on buses may be transferable to hydrogen.

A second concern when allocating public funds for AFV fueling stations is how to determine when such support is no longer needed. Complex issues are involved in defining success, and determining when it has been achieved. For example, several turnkey natural gas providers now consider high-throughput CNG and LNG stations to be commercially sustainable. This is the case largely due to government incentive funds that have encouraged HDV fleets to procure NGVs. Those same fleets may need additional government funding to offset higher operational costs. Fleets that don't consume large fuel volumes often need subsidization of both vehicles and fueling stations. Building public-access stations is costly and currently not always profitable for infrastructure providers; consequently, government funds may be needed if this feature is desirable. In summary, defining success and determining an exit strategy for government funding can be a complex, dynamic process.

These issues faced by government agencies funding AFV programs – how to avoid stranded investments and what criteria to use for exit strategies – require careful monitoring and dynamic response. The stakes are significant, given the magnitude of incentive funding available in California today for AFVs and fueling infrastructure. As described in this report, significant new uncertainties have recently emerged regarding price, supply and demand for virtually all transportation fuels. To determine which of these parameters could negatively impact AFV markets and lead to stranded infrastructure investments, each year it will be necessary to assess and update the latest trends. Similarly, it will be necessary to perform ongoing assessments of progress towards sustainable commercialization, to determine the appropriate points to phase out government investments. For these reasons, the Clean Fuels Market Assessment has been designed to be a "living" document.

However, the $6 million immediately available for 2001 allocations under the California Clean Fuels Infrastructure Development Plan is relatively small compared to the magnitude of infrastructure investments needed, by both government agencies and the private sector. Therefore, the recommendations in this Assessment are focused on the most promising infrastructure deployments that 1) most need government funds to become commercially self-sustaining, and 2) appear to entail reasonable risk that they won't lead to stranded investments.

[3] California Air Resources Board, Staff Report: Initial Statement of Reasons – Proposed Regulation for a Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses, January 27, 2000.

3. Status of Clean Fuel Vehicle Technologies in California

3.1 Near-Term Fuel / Vehicle Technologies for Potential Development

Over the last decade, alternatively fueled LDVs, MDVs, and HDVs using a wide range of technologies and fuels have been deployed in California. These include "flexible-fuel" vehicles using any combination of 85% methanol or ethanol blended with gasoline; "bi-fuel" light-duty vehicles that were designed to operate on a gaseous fuel or gasoline; and trucks and buses powered by "dedicated" methanol, propane or natural gas engines. In heavy-duty applications, many types of alternative-fuel engines have been successful in penetrating the market. However, these engines are still being deployed in insufficient numbers to achieve self-sustained commercialization. The major barriers to wide-scale commercialization have largely been (1) higher costs of the vehicles compared to conventional vehicles, and (2) higher costs and limited numbers of fueling stations. These barriers are closely related through a classic "chicken or the egg" problem, i.e., which will come first: adequate numbers of AFV fueling stations to stimulate production of AFVs, or sufficient sales of AFVs to justify the building of new alternative fuel stations?

As a prelude to the key issue of this Market Assessment – clean fuel infrastructure development – the following sections provide an overview of various AFV types that are now commercially available in California, or are expected to be introduced over the next five years.

3.1.1 Natural Gas Vehicles

Commercially Available Vehicles / Technological Maturity

Approximately 75 types of natural gas vehicles are commercially available today from U.S. engine and vehicle manufacturers. Available products have emerged recently in virtually all on-road applications, including transit buses; school buses; refuse haulers; street sweepers; light-, medium- and heavy-duty trucks and vans; and passenger cars. Table 4 lists the total number of natural gas vehicle (NGV) manufacturers and products that are offered for commercial sale, by each of these vehicle sectors.

The majority of NGVs on the road today are fueled by compressed natural gas (CNG), although vehicles fueled by liquefied natural gas (LNG) are becoming increasingly prominent in certain heavy-duty vehicle applications. Figure 3-1 shows a breakdown of the types of fleets in the United States that typically use CNG-fueled vehicles, by vehicle size and application. It shows that light-duty cars and pickup trucks are popular platforms for NGVs.[4] It also shows that state and local governments, as well as private fleets, are

[4] As the next table shows, bi-fuel vehicles are common in these applications, so minimal volumes of petroleum may be displaced.

significant users of heavy-duty vehicles fueled by CNG. These vehicles by design run on at least 85% natural gas.[5]

Table 4. U.S. NGV manufacturers and products

Product Category	Total # of Manufacturers	Total # of Products
Transit / Shuttle Buses	11	34
School Buses	5	8
Medium- and Heavy-Duty Trucks	8	12
Light-Duty Trucks and Vans	4	6
Passenger Cars	5	6
Off-Road Vehicles	8	9
Natural Gas Engines	13	32

Source: Gas Technology Institute, "NGVs – Year 2000 Report: Research, Development Demonstration and Deployment," 2000

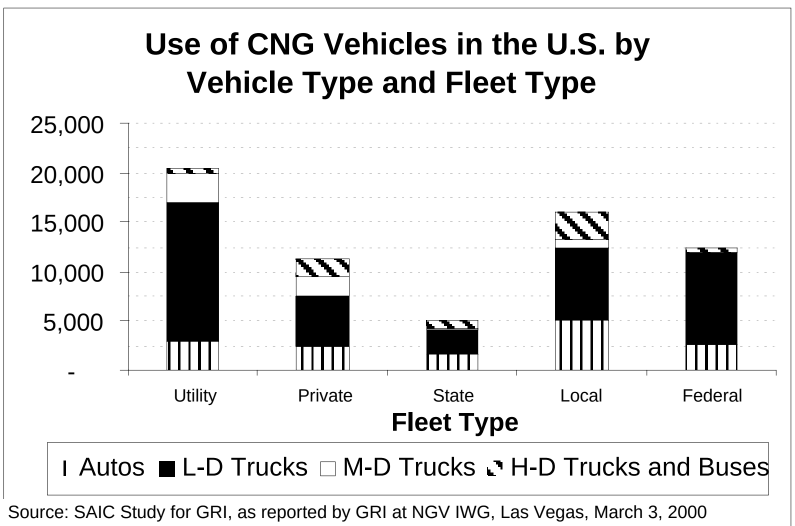


Figure 3-1. Number and type of CNG vehicles used by various fleet types (U.S.)

Table 5 lists recent-model CNG vehicles that are offered in California for light- and medium-duty applications.

[5] The diesel pilot Caterpillar C-12 natural gas engine from Power Systems Associates uses 15% diesel and 85% natural gas by volume.

Table 5. Recent model light- and medium-duty CNG vehicles in California

Maker	CNG Vehicle	Engine Displacement	Type of Natural Gas Engine
Ford	♦ Econoline E-450 Cut Away ♦ Econoline Van / Wagon ♦ F-Series Light Duty Pickup	5.4 Liter V8	Dedicated CNG
Ford	♦ Crown Victoria Sedan	4.6 Liter V8	Dedicated CNG
Daimler-Chrysler	♦ Ram Van / Wagon 2500 ♦ Ram Van / Wagon 3500	5.2 LiterV8	Dedicated CNG
Acura	♦ MDX SUV	3.5 Liter V6	Dedicated CNG
Honda	♦ Civic GX	1.7 Liter L4	Dedicated CNG
Toyota	♦ Camry Sedan[a]	2.2 Liter L4	Dedicated CNG
Ford	♦ F-Series Light Duty Pickup	5.4 Liter V8	Bi-Fuel CNG / Gasoline
GM	♦ Express / Savana	5.7 Liter V8	Bi-Fuel CNG / Gasoline
GM	♦ Chevy Cavalier Sedan	2.2 Liter L4	Bi-Fuel CNG / Gasoline

[a]The Camry was discontinued after the 2000 model year

Despite this variety of vehicle types and applications, the use of natural gas as a motor vehicle fuel has not increased as rapidly as predicted five years ago. One reason is that regulatory drivers for alternative fuels have been marginally effective. For example, the federal Energy Policy Act (EPACT) allows bi-fuel natural gas vehicles (i.e., capable of running on gasoline or natural gas) to be operated on gasoline while still qualifying as "alternatively fueled."[6] Affected fleets have therefore been slow to utilize the natural gas fuel option or incorporate dedicated natural gas vehicles, resulting in very low fuel use. This perpetuates the biggest barrier for natural gas vehicles: the fueling infrastructure remains very limited and under utilized. Today, there are approximately 180,000 gasoline stations in the U.S.[7] compared to only 1,200 natural gas vehicle fueling stations[8], of which about 240 are in California. Most of these are CNG stations, which have been especially expensive to build, operate and maintain. About 105 "public-access" CNG stations exist in California – these stations tend to dispense the lowest volumes of fuel, for reasons further described below.

To maximize the most favorable economics and address major regulatory drivers (see Appendix A: Air Quality Regulations and Petroleum Displacement), the focus of NGV commercialization is shifting towards fleets with heavy-duty trucks, transit buses, and refuse haulers. As Table 6 shows, on average natural gas vehicles in these categories consume thousands of gasoline-gallon equivalents (GGEs) of natural gas each year – significantly

[6] EPACT has been updated to require a 20% reduction in petroleum use by Federal fleets, but not necessarily through greater use of alternative fuels. See Footnote #22 on page 25.

[7] According to the United States General Accounting Office, February 2000.

[8] This refers to all CNG and liquefied natural gas (LNG) stations, excluding home-appliance sized CNG units.

more than natural gas vehicles in the light- and medium-duty categories.[9] HDVs are usually centrally fueled and maintained -- also conducive to natural gas engines and fuels.

Table 6. Largest fuel users by vehicle type / application.

Vehicle Class	Annual Miles per Vehicle	Miles Per Gallon (gasoline or diesel equivalent)[10]	Gallons per Year per Vehicle
Transit Buses	40,000	3.5 dge	11,430
Refuse Trucks	20,000	2.0 dge	10,400
HD Trucks (Class 6-8)	65,000	6.5 dge	10,000
Shuttle Vans	90,000	12.0 gge	7,500
Taxis	90,000	15.0 gge	6,000
School Buses	15,000	5.0 dge	3,000
MD Trucks (Class 3-6)	25,000	11.0 gge	2,270
LD Trucks	15,000	15.0 gge	1,000
Automobiles	19,200	24.0 gge	800
Source: Gas Technology Institute, "NGVs – Year 2000 Report: Research, Development Demonstration and Deployment," 2000			

This trend towards increased usage of natural gas in the heavy-duty sector is reflected in the growing number of low-emission heavy-duty natural gas engines that are commercially available. Table 7 lists the 1999 and 2000 model-year heavy-duty natural gas engines that have been certified to CARB's Optional Low-NOx Emission Credit Standards. To date, no conventionally fueled engines have achieved these standards.

The specific natural gas vehicle sectors that use these engines are growing rapidly, as Table 8 shows, and there have been some significant success stories. For example, natural gas engines now power approximately 6% of all existing U.S. transit buses; the greater Los Angeles metropolitan area currently has nearly 1,000 such buses.[11] CARB estimates that at least 18 transit districts in California now operate natural gas buses or plan to purchase them. Nationwide, about 20% of the new buses procured in 2000 are natural gas powered.[12] Many of the same engines that have been used in transit bus applications are also used in heavy-duty trucks. Over the last several years, the number of natural-gas-powered heavy-duty trucks in the U.S. has grown more than four fold (see Table 8).

[9] However, this table also shows that in certain applications such as taxicabs and shuttle buses, LDVs and MDVs can consume large amounts of fuel.

[10] GGE = gasoline gallon equivalent and DGE = diesel gallon equivalent (referring to energy content)

[11] Most of these are CNG buses at the Los Angeles County Metropolitan Transit Authority, but the Orange County Transit District has recently taken delivery of 61 LNG buses, under the first of several scheduled procurements.

[12] NGV Market Overview" information from "Natural Gas Vehicles Compendium of Market Studies and Research," GRI document #99/0077, RP Publishing, April 1999, Market data based on annual surveys conducted by Science Applications International Corporation.

Table 7. Recent heavy-duty natural gas engines certified to CARB's Low-NOx Emission Standards

MY	Manuf.	Service Type[a]	Fuel Type	Displ (ltr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	NMHC (g/bhp-hr)	Cert. Std. NOx/PM	HP
2001	Mack	HHD	L/CNG	11.9	1.8	.03	0.3	2.0/0.10	325
2001	DDC	UB	L/CNG	12.7	2.0	.02	0.8	2.5/0.05	330
2001	DDC	UB	L/CNG	12.7	2.0	.02	0.8	2.0/0.05	325
2001	Deere	MHD	CNG	6.8	2.4	.04	0.3	2.5/0.10	225
2001	Deere	MHD	CNG	8.1	2.2	.02	0.4	2.5/0.10	250
2000	Baytech	MHD	Dual[b]	5.7	1.3	--	0.00	1.5/NA	211/245
2000	Baytech	MHD	CNG	5.7	1.3	--	0.00	1.5/NA	211
2000	Baytech	HDG	Dual[b]	5.7	1.3	--	0.00	1.5/NA	211/245
2000	Baytech	HDG	CNG	5.7	1.3	--	0.00	1.5/NA	211
2000	Mack	UB/HHD	L/CNG[f]	11.9	2.3	0.03	0.3	2.5/0.05	325/350
2000	DDC	UB	L/CNG	12.7	2.0	0.02	0.8	2.5/0.05	330[g]
2000	DDC	UB	L/CNG	8.5	1.5	0.01	0.8	2.0/0.05	275
2000	Cummins	MHD	L/CNG	5.9	1.8	0.02	0.10	2.5/0.10	150/195/230
2000	Cummins	HHD	CNG	8.3	1.8	0.02	0.6	2.5/0.10	250/275
2000	Deere	MHD	CNG	8.1	2.2	0.02	0.4	2.5/0.10	225/250
2000	Deere	MHD	CNG	6.8	2.4	0.04	0.3	2.5/0.10	225
2000	PSA[d]	MHD	Dual [e]	7.2	2.2	0.08	1.2	2.5/0.10	200/240/250
2000	PSA[d]	HHD	Dual [e]	10.3	2.4	0.06	1.1	2.5/0.10	305/350
2000	PSA	HHD	Dual	12.0	2.4	0.10	0.5	2.5/0.10	370/410

[a]Service Type: MHD (Medium Heavy-Duty); HHD (Heavy Heavy-Duty); UB (Urban Bus); [b] Dual fuel (CNG + gasoline);
[c]Total Hydrocarbons; [d]Power Systems Associates (using Caterpillar engines); [e]Dual Fuel (CNG + Diesel; or LNG + Diesel)
[f] L/CNG: Liquefied Natural Gas or Compressed Natural Gas; [g] It also believed that the 400 HP version of the DDC 12.7 L engine (Series 60G) is certified to the low-NOx standard for HHD applications, but this has not yet been confirmed by CARB staff.

Source: California Air Resources Board website, updated 3/21/01

Table 8. U.S. Growth of NGV populations in the heavy-duty vehicle sector

Type of Heavy-Duty Vehicle	1996	2000	Growth
Buses (Transit, School, Others)	1,800	5,000	180%
Medium-Duty Trucks	4,600	7,500	63%
Heavy-Duty Trucks	400	2,200	450%

Source: NGV Market Overview, presented to the GTI-IWG by R.Gable of GTI, October 2000[13]

The numbers of vehicles fueled by liquefied natural gas (LNG) are expected to increase at an even more rapid rate than CNG-fueled vehicles (Table 9). The key differences and opportunities for these two types of natural gas vehicles are discussed further in this Market Assessment, in the context of infrastructure development.

[13]NGV Market Overview", Information from "Natural Gas Vehicles Compendium of Market Studies and Research," GRI document #99/0077, RP Publishing, April 1999, Market data based on annual surveys conducted by Science Applications International Corporation

Table 9. U.S. Growth of CNG and LNG Vehicles

Time Period	CNG Vehicles (All Vehicle Types)	LNG Vehicles (HD Trucks and Buses)
End of 1996 (actual)	54,700	N/A
End of 1999 (actual)	72,000	~1,000
By End of 2001 (expected)	90,000	>1,300
Anticipated Increase: 1999 to 2001	25%	>30%

Source: NGV Market Overview, presented to the GTI-IWG by R.Gable of GTI, October 2000

It's expected that California will continue to lead the accelerated deployment of NGVs, especially LNG vehicles in the heavy-duty sector. According to an LNG market assessment recently performed for Arthur D. Little by Zeus Development Corporation[14] and surveys conducted by Gladstein & Associates[15], the number of LNG vehicles in California is expected to increase from approximately 135 in 1999 to 653 by the end of 2001. New LNG buses (267) will show the largest increase, followed by HD trucks (133) and refuse hauler trucks (118). These projections are shown in Figure 3-2. Air quality regulations such as SCAQMD's 1190 Series of fleet rules are among the unique drivers in California that are expected to play key roles in expanding use of LNG-fueled HDVs (see Table 14 further ahead in this section).

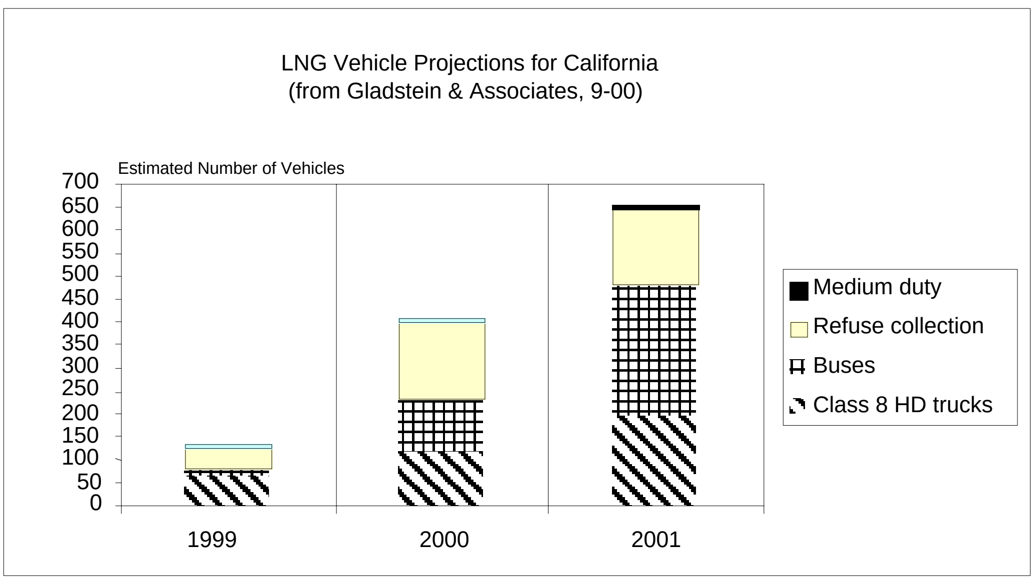


Figure 3-2. Estimated Near-Term Growth of LNG Vehicle Populations in California

[14] Market Assessment of LNG as a Transportation Fuel for Vehicles in California, Zeus Development Corporation, July 2000, for Arthur D. Little under work sponsored by the Gas Technology Institute and Brookhaven National Laboratory.

[15] LNG as Heavy Duty Vehicle Fuel Project: Final Report, Gladstein & Associates, September 2000, for Arthur D. Little under work sponsored by the Gas Technology Institute and Brookhaven National Laboratory.

Vehicle Range and Fuel Economy

Two principal engine types are available for natural gas vehicles: 1) spark ignited (dedicated or bi-fuel), and 2) diesel pilot ignited. The real-world driving range for natural gas vehicles depends on which engine type is used, and many other factors that include the following:

- Size, weight (including load) and type of vehicle (light-, medium- or heavy-duty)
- Specific application (e.g., transit bus, refuse hauler, shuttle van)
- Vehicle duty and drive cycle
- Type of fuel used (CNG, LNG)
- On-board fuel storage capacity (volume per tank, number of tanks)
- Volumetric efficiency of engine

The efficiency variable alone is highly dependent on vehicle duty cycle (i.e., the amount of idling, stop-and-go versus driving at highway speeds). Because of these many variables and a general lack of verifiable data on AFVs in real-world use, it is difficult to present absolute values for driving ranges of NGVs. As a general rule, field demonstrations of vehicles with spark-ignited heavy-duty natural gas engines have shown an efficiency penalty of about 25 to 30 percent compared to compression-ignited (diesel) engines, while diesel-pilot-ignited natural gas engines are about 5 to 10 percent less efficient then diesel. However, this varies by manufacturer, and new technology is being developed continually. According to Cummins Engine Company, its spark-ignited alternative fuel engines currently exhibit an efficiency loss of 10 to 25 percent, but Cummins expects this to be reduced in the next five years based on "continued improvement" of its products."[16] John Deere uses a proprietary low-throttling-loss technology in its CNG-fueled 8.1 liter engine. A current test of refuse haulers in Irvine California has shown that this engine can achieve equivalent thermal efficiency to diesel engines used in comparable refuse trucks.[17]

Table 10 provides an overview of estimated range data for various dedicated NGV types versus the diesel or gasoline vehicle from which they were derived, or most closely resembles them.

[16] E-mail from Edward J. Lyford-Pike,Chief Engineer, Advanced Engineering, Alternative Fuels, Cummins Engine Company, to Jon Leonard of Arthur D. Little, 12/12/00.

[17] Arthur D. Little, Data Collection and Evaluation for John Deere Corporation's Demonstration of CNG-Fueled Refuse Haulers at Waste Management, Inc. , Final Report, March 5, 2001

Table 10. Estimated driving ranges for selected dedicated NGVs

NGV Type	Range on Baseline Vehicle	Range on Closest NG Version	% Reduced Range from Baseline
Honda Civic CNG	~450 miles	200-225 miles	50 to 56%
Ford E-250 CNG Van (Standard)	580	150 to 275 miles	53 to 74%
Ford E-250 CNG Van (Extended Range)	580	250 to 425 miles	27 to 57%
CNG Transit Bus with DDC Series 50G Engine	400	300	25%
LNG Class 8 Semi Tractor with DDC Series 60G Engine	~600	~450	25%

Source: Ranges for baseline vehicles are from combined city/highway estimates from Edmunds.com, where available, and from diesel controls in HDV demonstrations. Ranges for NGV versions were obtained from vehicle manufacture literature, the NGV Coalition's Natural Gas Vehicle Purchasing Guide, and HDV demonstrations.

Range can be a very important vehicle-selection criterion. It's a primary factor in determining how vehicles can be used, and the routes they can serve, which are especially important issues for fleet managers. For example, Table 11 lists two survey respondents who operate fleets with an average vehicle range of at least 250 miles. Both would seek "equivalent range" from clean-fuel vehicles before purchasing them. Maximizing the range of NGVs (as well as virtually all types of AFVs) is very important to achieving their full commercialization potential. Vehicles that provide less than an acceptable range[18] are likely to be relegated to restricted use in "niche" applications that ultimately may not significantly advance commercialization efforts for that particular vehicle type and its fueling infrastructure.[19]

Table 11. Survey input from end users on average fleet vehicle range

Fleet / End User	Average Fleet Vehicle Range on Baseline Vehicles	Comments
City of Freemont	250-300 miles (inter-city routes)	Lack of equivalent range is an "existing utilization barrier"
Freemont Unified School District	300 miles (suburban routes)	Lack of equivalent range is an "existing utilization barrier"

[18] "Acceptable" range varies by fleet, application and other factors. For typical medium-duty applications, as a rule of thumb at least a 180-mile range is needed to operate the average vehicle with full utility.

[19] For example, in one current demonstration of Class 8 LNG trucks, the reduced range (about 25%) of the LNG trucks has restricted their use to local deliveries, while the diesel control vehicle makes interstate deliveries with much higher monthly mileage accumulation. Also, reduced range of CNG buses versus diesel buses has been a significant issue with some transit districts.

Vehicle and Engine Costs

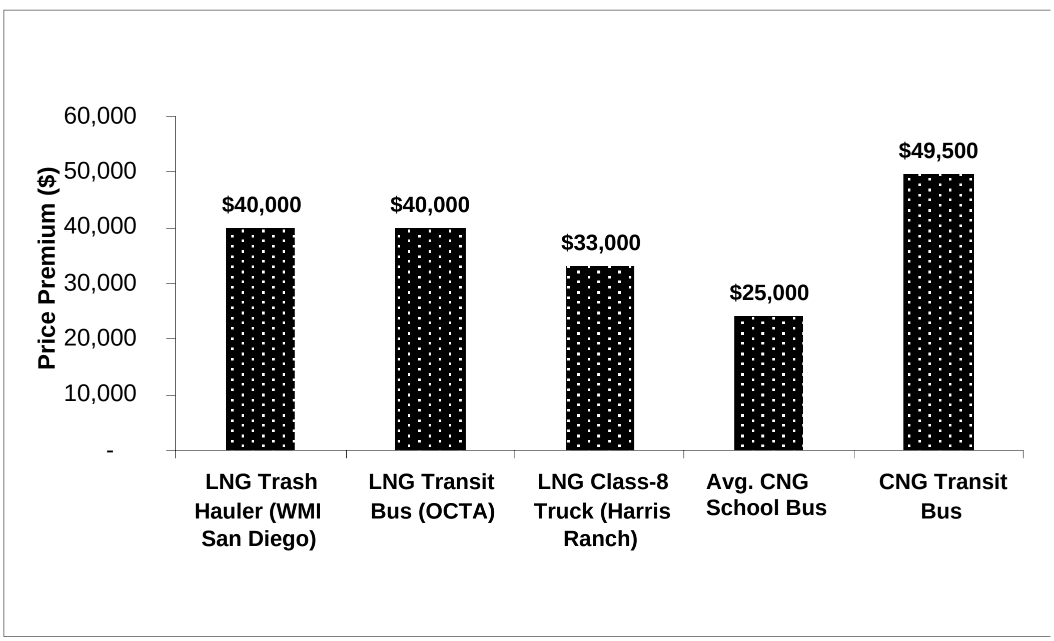
Natural gas vehicles currently cost significantly more than their gasoline and diesel counterparts. This is largely due to the higher costs of purchasing and installing the fuel storage systems. Virtually all light- and medium-duty NGVs run on CNG, requiring on-board storage of compressed gas in high-pressure cylinders. These CNG tanks are manufactured from steel, fiberglass-reinforced steel, fiberglass-reinforced aluminum or 100% composite materials. Because they are designed for working pressures of 3,000 or 3,600 psi, CNG tanks are much heavier and more expensive than gasoline or diesel fuel tanks per amount of energy stored.

Table 12 lists the approximate incremental costs of several commercially available light- and medium-duty CNG vehicles.

Table 12. Incremental cost of selected light- and medium-duty CNG vehicles

Light- / Medium-Duty CNG Vehicle	Approximate Incremental Cost
Honda Civic GX	$4,500
Dodge Ram Van 2500	$7,800
Ford E-Series Van	$5,000 to $6,000

Source: Edmunds.com and manufacturer literature



Sources: survey input, Carl Moyer program applications, and discussions with manufacturers, etc.

Figure 3-3. Incremental cost (over diesel version) of selected natural gas HDVs

Heavy-duty NGVs are commercially available in both CNG and LNG configurations. The total incremental cost of such vehicles typically ranges from about $24,000 to $50,000. The engine component of this differential cost is typically about $15,000 to $20,000, regardless of whether CNG or LNG is the fuel. However, heavy-duty CNG vehicles usually have a higher price premium than LNG vehicles using the same engine. For example, Figure 3-3 indicates that the incremental cost of an LNG-fueled transit bus is about $9,500 less than the incremental cost of an equivalent CNG-fueled transit bus. This is largely due to the higher cost of CNG storage on an energy equivalent basis. Still, on-board storage of LNG is expensive; a typical LNG truck configured with two cryogenic 119 gallon LNG tanks costs about $20,000 ($6,000 per tank, plus installation). A diesel fuel tank with capacity to carry the same amount of energy is significantly less expensive.

Although heavy-duty natural gas vehicles cost significantly more than comparable diesel vehicles, most use engines that are certified to CARB's Optional Low-NOx Emission Credit Standard. As a result, fleets are eligible to receive funds from various sources (e.g., the Carl Moyer Program, AB 2766, CMAQ, Discretionary) to offset the higher capital costs of these engines. Current price premiums are largely a function of low manufacturing volumes. Cummins Engine Company indicated that the incremental cost of its C8.3G and B5.9G natural gas engines would be significantly reduced if sold in larger volumes, and these engines could cost less than their diesel counterparts if sold at equivalent volumes.[20]

Advanced Vehicle Research, Development and Demonstration (RD&D)

Several major programs are underway to improve the commercial viability of natural gas vehicles, especially in the heavy-duty sector. These programs involve a wide variety of public and private entities, but all are basically designed to address the following parameters: 1) improve performance, power density and efficiency, 2) further reduce emissions, 3) reduce cost, 4) broaden product offerings, and 5) improve on-board fuel storage options and increase energy volumes. Table 13 summarizes some of the major existing RD&D efforts involving natural gas vehicles, which are designed to address these needs.

[20] E-mail from Edward J. Lyford-Pike,Chief Engineer, Advanced Engineering, Alternative Fuels, Cummins Engine Company, to Jon Leonard of Arthur D. Little, 12/12/00.

Table 13. Examples of major RD&D efforts to improve NGV commercial viability

Name of RD&D Program	Participants	Major Program Objective(s)	Timeframe
Next-Generation Natural Gas Vehicle	Government-industry consortium headed by DOE-NREL, with 33 other agencies / companies / organizations	Design, develop, and evaluate prototype high-efficiency NGV platforms for: • Class 3-6 CNG (MDV) • Class 7-8 LNG (HDV)	Build prototype Class 3-6 CNG and Class 7-8 LNG vehicles by 2004
Low-NOx Heavy-Duty Natural Gas Engine Program (Contract #1)	Energy Commission, DOE-NREL, SCAQMD, Cummins Engine Company, Westport Innovations	Develop, certify and commercialize diesel-pilot (High Pressure Direct Injection) ISX engine, at or below 0.5 g/bhp-hr NOx	Certify engine by late 2002
Low-NOx Heavy-Duty Natural Gas Engine Program (Contract#2)	Energy Commission, DOE-NREL, SCAQMD, Detroit Diesel Corporation	Develop, certify and commercialize dedicated engine at, or below 0.5 g/bhp-hr NOx	Certify engine by late 2002
Gas Technology Institute Infrastructure Working Group	Government-industry consortium headed by DOE and GTI, with ~ 25 other agencies / companies / organizations	Miscellaneous projects to improve on-board storage of CNG and LNG fuel	Ongoing over next two years
Dedicated LNG ISX Engine for Class 8 Trucking	Cummins Engine Company, Westport Innovation	Demonstrate low-NOx LNG trucks with 15-liter ISX engine in California and Canada	Beginning in 2001

Projection of NGV Populations by 2005

Based on existing regulatory drivers and incentive programs, and the number of commercial offerings available, there will be high demand for natural-gas-powered HDVs in California for at least five years, and possibly beyond. Regulatory drivers include CARB’s Transit Bus Fleet Rule and the South Coast Air Quality Management’s “1190 Series” of fleet rules. Table 14 lists SCAQMD’s adopted or proposed fleet rules affecting HDVs. It indicates that roughly 16,000 new HDVs to be purchased under five fleet rules will be candidates for alternative fuels. Currently, heavy-duty engines certified to California’s optional low-NOx credit standard are predominantly fueled by CNG or LNG. However, the actual number and rates of NGVs introduced under these rules will be affected by 1) phase-in rates and exemptions, 2) availability of various engines and vehicles, 3) fleet turnover rates, and 4) available funding for vehicles and infrastructure. On average, full phase-in of these rules is expected to occur between 2010 and 2015.

Table 14. SCAQMD's adopted or proposed fleet rules affecting HDVs

SCAQMD Fleet Rule No.	Targeted Fleet Type(s)	Estimated SCAB HDV Population for Potential Conversion to Alternative Fuels
1192	Transit Buses	5,000
1193	Refuse Haulers	6,000
1194	Airport Support Vehicles	500
1186.1	Street Sweepers	700
1196	Heavy-Duty Public Fleets	4,100
Total		**16,300**

Sources: SCAQMD staff reports on fleet rules, and personal communication from David Coel, SCAQMD, to Jon Leonard, ADLittle on 3/27/01

For transit buses, there is major overlap between the requirements of SCAQMD's Rule 1192 and CARB's Public Transit Bus Fleet Rule. As of March 2001, 66 of California's 75 transit agencies have declared that they will comply with CARB's rule by taking either the "diesel path" or "alternative fuel path." Forty of those 66 have selected the diesel path, while 26 have declared the alternative fuel path. Based on these preliminary estimates, about 2,700 of the 6,800 buses to be purchased under requirements of the rule will be alternative fueled.[21] A large majority of those will be natural gas buses purchased by transit districts in the South Coast Air Basin, to meet the requirements of SCAQMD's Rule 1192.

For LDV and MDV markets, SCAQMD's fleet rules are unlikely to be strong drivers toward NGV purchases, since those rules allow requirements to be met with the lowest-emitting gasoline vehicles. California's recent modifications to the Zero-Emission Vehicle program require automakers to produce about 100,000 "other" clean vehicles in 2003, with this number increasing to more than 400,000 by 2006. Vehicles like Honda's CNG-powered Civic, which has been declared the first Advanced Technology Partial Zero-Emission Vehicle (AT-PZEV), may prove to be cost-effective ways to meet these obligations. However, the same holds true for advanced gasoline vehicles. Meanwhile, unless energy-related regulations such as EPACT are modified to include fuel-use requirements,[22] they are unlikely to stimulate sales of dedicated NGVs or natural gas fuel. In sum, compared to the HDV sector, there is greater uncertainty about the numbers of LDVs and MDVs that are likely to actually use natural gas by 2005, and help expand the CNG (or L/CNG) infrastructure.

3.1.2 LPG (Propane) Vehicles

LPG (also known as "propane," in reference to its primary constituent) has long been one of the most widely used alternative fuels, including use in the transportation sector. Worldwide, it is estimated that 2.5 million vehicles use LPG fuel; about 500,000 of these are located in

[21] Fax from Alvaro Gutierrez, California Air Resources Board, to Jon Leonard on April 10, 2001.

[22] Executive Order 13149 (April 2000) requires Federal agencies to "develop a strategy" to reduce petroleum consumption by 20% by 2005. This can be achieved by increasing fleet fuel efficiency or reducing miles traveled, as well as by using alternative fuels. (Source: http://www.ott.doe.gov/epact/pdfs/exorder13149.pdf.)

the United States. Commercial fleets in applications such as pickup trucks, taxis, buses, airport shuttles, and forklifts operate approximately 60% of the LPG vehicles in the United States.[23]

Commercially Available Vehicles / Technological Maturity

Commercial offerings of LPG-fueled cars and light trucks have been mostly limited to bi-fuel vehicles, which can run on either LPG or gasoline using the same engine but separate fuel systems. Bi-fuel engines are convenient to the fleet operator, but they significantly compromise emissions and slightly compromise efficiency. This is because bi-fuel systems do not allow optimization for the clean-burning, excellent combustion characteristics of LPG. In recent model years, two medium-duty LPG vehicles have been available in California, and both use bi-fuel engines (see Table 15). Caltrans (state of California) recently purchased 678 Ford F-150 bi-fuel pickups, and has ordered 300 additional vehicles. The actual volume of propane that Caltrans has consumed in these bi-fuel vehicles has been minimal, according to propane suppliers. However, that may change because the State has established a policy to be a leader in the use of alternative fuels. Caltrans officials have recently expressed interest in using its fleet of F-150 pick-ups to anchor new propane stations, to be built by Clean Fuel USA (see Section 4.3).[24]

Table 15. 2001 MY medium-duty LPG ULEVs available in California

Manufacturer	Model	Fuel	Emissions Certification
Ford	F-150 Pickup	LPG / Gasoline	ULEV[a]
Ford	F Series Super Duty	LPG / Gasoline	ULEV[a]

Source: NREL Alternative Fuels Data Center website (http://www.afdc.nrel.gov)

[a] NREL lists the emissions certification as ULEV, although this vehicle is not listed on the CARB website as ULEV certified in California.

In addition to these bi-fuel vehicles, GM recently began selling one of the first dedicated-propane, medium-duty trucks from an original equipment manufacturer.[25] Table 22 provides an overview of this vehicle.

[23] Source: Website of the National Alternative Fuel Training Consortium (http://naftp.nrcce.wvu.edu/).

[24] Personal communication from William Platz, Delta Liquid Fuels, to Jon Leonard on April 2, 2001. Platz, a principal in Clean Fuel USA, is working with Caltrans on this plan.

[25] The certification of this engine family is in the name of Impco, which makes the propane-specific hardware and software for the engine.

Table 16. GM / Impco's dedicated propane medium-duty truck for 2001.

MY	Manu-facturer	Service Type	Fuel	Engine Type / Displacement	Certification	Typical Uses
2001	GM	Medium-Duty Cab Chassis	Dedicated LPG	Vortec 8100 / 8.1 L	LEV 50 State	School bus, open bed, closed box, general cargo

Sources: GM website (http://www.gmaltfuel.com) and NREL AFDC website (www.afdc.nrel.gov)

NOTE: GM will reportedly sell a full-sized dedicated LPG van in the 2002 model year.

Two commercially available, dedicated LPG engines have recently been certified to California's heavy-duty optional low-NOx credit standards (see Table 17). These are among the lowest-emitting heavy-duty engines available in the world, and can work in a variety of medim-heavy duty applications (on-road and off-road). For example, the Cummins B5.9 engine is a versatile powerplant that can be used in a variety of medium heavy-duty applications. These include large pickups; small school buses; vehicles operated by transit properties including shuttle buses; step vans; delivery trucks; and port vehicles such as yard hostlers. The LPG version of the B5.9 engine (195 hp) is available throughout North America, and there are significant numbers in revenue service.

Table 17. Recent H-D dedicated LPG engines certified to Low-NOx Standards

MY	Manu-facturer	Service Type[a]	Fuel	Displace-ment (ltr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	NMHC (g/bhp-hr)	Cert. Std. NOx/PM	HP
2000	IMPCO	MHD	LPG	7.4	0.8	--	0.66	1.5/NA	229
2000	Cummins	MHD	LPG	5.9	2.3	0.01	--	2.5/0.10	195

[a]Service Type: MHD (Medium Heavy-Duty8,500 26,000lb. GVWR)
[c]Total Hydrocarbons

Source: California Air Resources Board website and Executive Orders

A second heavy-duty LPG option is offered by IMPCO, which sells a certified after-market LPG kit for the 7.4 liter GM engine that provides exceptionally low NOx emissions.

Vehicle Range and Fuel Economy

A gallon of propane contains about 71% and 65%, respectively, of the energy found in a gallon of gasoline and diesel. Like spark-ignited natural gas vehicles, LPG engines are somewhat less efficient than gasoline and diesel engines. A typical medium-duty propane vehicle holds about 15 gallons of fuel, in a single tank weighing about 138 pounds and taking up 2.0 cubic feet of space.[26] Options are available to add a second fuel tank and approach the energy storage of an equivalent gasoline vehicle, although this increases vehicle weight and takes up space on the chassis. The net result is that LPG vehicles can provide equivalent range to conventionally fueled vehicles, at the expense of lower fuel economy and slightly less cargo space.

[26] Western Propane Gas Association, A Few Reasons Why Propane is the Leading Clean Air Vehicle Fuel, supplement to "Technical Resource Guide" handed out by the San Diego Regional Clean Fuel Coalition at the 2000 Clean Cities national meeting.

Vehicle/Engine Cost

The costs and prices of LPG vehicles are similar to those of CNG vehicles, although onboard LPG fuel tanks are less expensive than CNG tanks. Light- and medium-duty LPG vehicles are typically priced about $4,000 to $5,000 more than the gasoline vehicles from which they are derived. Table 18 lists the estimated incremental costs of three commercially available LPG vehicles (bi-fuel and dedicated). The incremental cost for the shuttle bus is primarily due to its Cummins B5.9LPG engine, which is currently sold in low volumes and carries a significant price premium over the Cummins' diesel B5.9 (ISB) engine, or even the natural gas version (B5.9G), due to smaller volume production. This has been a significant barrier to deploying greater numbers of this extremely clean, dedicated LPG engine.

Table 18. Incremental costs of selected LPG vehicles

Vehicle Name / Type	Fuel and Engine	Incremental Cost
Ford F-Series Super Duty / Medium-Duty Truck	Bi-Fuel Triton 6.8 L	$5,245
GMC Pickup / Medium-Duty Truck	Dedicated Vortex 8.1 L	$4,000
Shuttle Bus	Dedicated Cummins B5.9LPG	$15,000[a]

Source: NREL AFDC website (http://afdc.nrel.gov)
[a]Estimated based on information from Cummins Engine Company and other sources

Advanced LPG Vehicle RD&D

An advanced type of bi-fuel LPG vehicle is being developed by General Motors and GFI Control Systems; the targeted application will reportedly be fleet vehicles such as police cars and taxicabs. Similar efforts are underway by other automakers. Also, the U.S. Department of Energy is reportedly working with one or more auto-manufacturer to develop an advanced, dedicated LPG vehicle fully optimized for low emissions and high performance (high range and power, etc.). At this time, however, the time frame for commercial introduction of these LPG vehicles has not been announced. The Los Angeles Department of Transportation is demonstrating two hybrid-electric transit buses powered by LPG-fueled Capstone microturbines. If successfully demonstrated, this type of advanced powertrain could significantly advance the potential for wider use of LPG in key heavy-duty vehicle applications.[27] For example, the Orange County Transit Authority still operates on-site propane stations and is considering deploying LPG hybrids with dual 75 kW Capstone microturbines.[28]

Projection of LPG Vehicle Populations by 2005

LPG has proven to be an exceptionally clean-burning fuel in dedicated heavy-duty engines, and greater deployment could yield both significant emissions and major displacement of gasoline and diesel fuels. A significant challenge involves getting major vehicle and engine

[27] Capstone recently announced that CARB has certified its microturbine fueled by LPG, CNG and diesel for use in commercial HEVs, such as those demonstrated at LADOT.

[28] Jim Ortner, OCTA, personal communication to Jon Leonard, April 4, 2001.

manufacturers to build dedicated LPG platforms that are affordable and optimized for the fuel's excellent combustion characteristics. This appears to be underway, to a limited extent.

It's difficult to estimate the number of LPG vehicles that are likely to be on the road by 2005 in California. In part, this depends on what role bi-fuel vehicles will continue to play. Large fleets such as Caltrans that operate hundreds of bi-fuel F-150 pickups can help displace petroleum fuels, but only if propane is used instead of gasoline. Currently, there are no strong energy-related drivers or incentives toward this end. Air-quality drivers such as SCAQMD's fleet rules and CARB's modified ZEV rule may help deploy dedicated propane vehicles, but that will depend on the degree to which vehicle and engine manufacturers commit resources to that particular fuel / technology combination.

3.1.3 Electric Vehicles

In 1990, CARB adopted the Zero-Emission Vehicle (ZEV) mandate, which effectively required that 10% of the new cars offered for sale in California by 2003 would be powered by battery-electric propulsion systems.[29] Over the last decade, the ZEV requirement has undergone "biennial reviews" by CARB. At the most recent review in September 2000, CARB staff proposed a number of significant modifications to the program, which were adopted by the Board on January 25, 2001. These changes were designed to maintain mandated production of ZEVs, while giving automakers greater flexibility in meeting individual requirements, as long as equivalent overall emissions reductions can be achieved.

Commercially Available Vehicles / Technological Maturity

Table 19 lists the light- and medium-duty EVs that have recently been available for lease or sale in California.[30] These EVs offer varying ranges and battery types to meet several types of market niches. According to recent CARB estimates, the six major automakers (General Motors, Ford, Daimler Chrysler, Toyota, Nissan, and Honda) have produced about 4,100 of these "pure ZEVs" for the California market, to date.[31] Each of these has been powered by a battery-electric propulsion system, which is currently the only commercially available technology that satisfies the ZEV definition. As a result of agreements signed between CARB and certain automakers, many of these EVs have been equipped with advanced batteries.

[29] It has always been recognized by CARB that other zero-emission technologies might eventually emerge, such as direct-hydrogen fuel cell vehicles, to enable automakers to meet their ZEV obligations. However, "ZEV" and "battery EV" have essentially been synonymous to CARB when discussing the early years of the program.

[30] All these EVs were reportedly available in 2000 (with the exception of the Honda EV PLUS), but many interested customers have claimed that they have been unable to actually obtain vehicles.

[31] California Air Resources Board, About EVs, http://www.zevinfo.com, information "as of March 2000."

Table 19. EVs recently offered in California

Make / Model of Recently Offered* EV	Battery Technology	Driving Range City / Hwy (miles)**
Gen II GM EV-1	Advanced Lead Acid	111/113
Gen II GM EV-1	Nickel-metal Hydride	143/152
Chevrolet S-10 Pickup	Nickel-metal Hydride	92/99
Chevrolet S-10 Pickup	Lead Acid	46/43
Honda EV PLUS	Nickel-metal Hydride	125/105
Ford Ranger Pickup	Nickel-metal Hydride	94/86
Ford Ranger Pickup	Lead Acid	84/69
Toyota RAV4	Nickel-metal Hydride	142/116
Nissan Altra EV	Lithium Ion	120/107
Chrysler EPIC Van	Nickel-metal Hydride	92-97
Chrysler EPIC Van	Lead Acid	70/65
Solectria FORCE	Lead Acid	58/50

NOTE: this list excludes low-speed vehicles, including those that are street legal.

*Current availability of these EVs is very limited, and varies by make / model

**Based on standardized tests

Source: California Air Resources Board, About EVs website, http://www.zev info.com, 3/6/01.

Vehicle Range

Reduced driving range compared to conventional vehicles is a major shortfall of current–technology battery EVs. Table 19 above provides estimated ranges for recently available EVs.

Vehicle Cost

Perhaps the most controversial aspect of California's ZEV regulation has involved how much it will cost to manufacture EVs in small and large volume production, and what their incremental cost will be to end users. A wide range of estimates have been made from both proponents and critics of the ZEV regulation, but it is generally accepted that battery-electric EVs will cost significantly more to manufacturer than conventional vehicles, at least until high-volume production is achieved and key technological advancements are realized. Currently, the main cause of higher EV costs are the battery packs, although the battery industry anticipates significant cost reductions over the next decade.[32]

Advanced Electric Vehicle RD&D

Many efforts are underway by major automakers to develop and commercialize advanced EVs designed for high efficiency and increased driving range, among other attributes.

[32] Menahem Anderman, Fritz R. Kalhammer and Donal MacArthur, Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost, and Availability, Prepared for the California Air Resources Board, June 2000.

Concept vehicles such as the Chevrolet Triax are being developed for advanced modular design using light-weight composite materials, with the major goals being increased vehicle efficiency and range at reduced manufacturing costs. The timeframe for commercialization of these advanced battery EVs depends largely on progress by the battery industry to lower manufacturing costs and achieve greater specific energy, which is the major parameter determining vehicle range.

In addition to "pure-battery" EVs, hybrid electric vehicles (HEVs) are also being developed by many automakers. These vehicles offer the advantages of electric drive (high torque and increased efficiency at low speeds) while providing performance and range equivalent to or better than conventional vehicles. Honda recently launched the first commercially available gasoline-electric hybrid, the Insight, which delivers 70 miles per gallon and offers a driving range of about 700 miles. Toyota has also started selling its own gasoline hybrid electric, the Prius. However, these near-term HEVs do not use alternative fuels or charge from the electricity grid. Therefore, as yet there are no clean fuel infrastructure implications to their wide-scale use.

Over the longer term, HEVs are expected to be introduced that use clean fuels and/or charging from the grid. The infrastructure implications of these technologies will be similar to other vehicles that use clean fuels or EV charging stations. The Electric Power Research Institute (EPRI) has assembled a working group to compare the impacts and benefits of various HEV options. The scope of work includes evaluation of the following areas: 1) HEV architecture, performance, modeling; and impacts; 2) costs; 3) customer preference; and 4) commercialization issues. The working group focused on a mid-size vehicle platform, although additional data is being collected on small car and SUV platforms. Results of the study are expected by mid 2001.

Fuel cell vehicles are another type of EV that offer special promise for commercial deployment – this is discussed in the next section, covering medium-term technologies.

Projection of EV Populations by 2005

The timeframe for full (self-sustaining) commercialization of battery EVs will probably be a function of two key factors: 1) regulatory stability, and 2) competition from other technologies that can provide equivalent emissions benefits. Regarding the first factor, the California Electric Transportation Coalition estimates that EVs will achieve full commercialization no later than 2010 "if regulatory factors remain stable."[33] A key uncertainty was recently clarified when CARB voted to hold firm on the ZEV mandate, even though modifications were made that may result in fewer "pure ZEVs" produced in the early years. Among other modifications, auto manufacturers will be allowed to meet their 4% ZEV obligations with a 50-50 split of ZEVs (essentially battery electric) and vehicles that use "advanced technologies" and/or cleaner fuels. CARB now estimates that the total number of ZEVs deployed in 2003 will vary from 4,450 to 15,450, depending on the type of ZEVs the

[33] Survey response received from Cecile Martin, Deputy Executive Director, California Electric Transportation Coalition, December 2000.

individual automakers chose to bring to market.[34] A reasonable guess is that approximately 10,000 EVs will be on the road in California by 2005.

One conclusion from CARB's recent review of the ZEV program is that new incentives are needed to make the production, marketing and purchase of EVs more attractive. To meet this need, the Zero Emission Vehicle Incentive Program (Assembly Bill 2061) will provide $18 million statewide to reduce cost of CARB-certified ZEVs bought or leased on or before December 31, 2002. On December 7, 2000, CARB approved guidelines for implementation of this program. Individual air districts are now eligible to submit an application to CARB to implement this program locally and receive funds. While matching funds are not required from air districts, CARB has further encouraged them to provide additional incentives for ZEVs and infrastructure.

3.1.4 Ethanol-Fueled Flexible Fuel Vehicles

Commercially Available Vehicles / Technological Maturity

Flexible-fuel vehicles (FFVs) powered by ethanol[35] have been offered in the United States by major manufacturers for several years. As Table 20 shows, at least eight auto manufacturers have recently offered FFVs that run on E85. Similar models are offered for the 2001 model year. On the heavy-duty vehicle side, the Los Angeles County Metropolitan Transit Authority operated several hundred "neat" ethanol (E95 or E100) transit buses in the mid 1990s. However, those particular buses were either retired or converted back to diesel operation, due to higher fuel and maintenance costs, as well as a lack of product support from the bus and engine manufacturers.

Table 20. Recent model year E85 FFVs

Manufacturer	Available Models and Years
Chevrolet	All 2000 2.2L S-10 pickups
Chrysler	1998-2000 3.3L minivans
Dodge	All 1998-2000 3.3L minivans
Ford	2000 3.0L Taurus LX sedans (and no cost option on SE and SES series)[36]
Ford	All 1999-2000 3.0L Ranger pickups
GMC	All 2000 2.2L Sonoma pickups
Mazda	All 1999-2000 3.0L B3000 pickups
Plymouth	All 1998-2000 3.3L minivans

Source: National Ethanol Vehicle Coalition website (www. E85fuel.com/ffvs.htm)

[34] Source: CARB website, (http://www.arb.ca.gov/newsrel/nr012601.htm), 3/6/01.

[35] Ethanol FFVs are capable of running on a blend of 15% gasoline and 85% ethanol (E85), or any mixture of E85 and gasoline. Essentially the same engine technology is used in FFVs that operate on methanol (M85).

[36] Also, many 1995-1999 3.0 L Taurus Sedans were FFVs

Range and Fuel Economy

E85 is a relatively high-octane fuel that contains about three fourths as much energy as gasoline (approx. 82,000 Btu per gallon). When driven on E85, this translates to a proportional reduction in driving range (assuming the same size fuel tank) for FFVs compared to similar gasoline-powered vehicles. Estimates for mid-sized vehicles indicate that more than 350 miles can be driven on an 18-gallon tank of fuel. FFVs operating on E85 get a horsepower boost of approximately 5%-7%.[37]

Vehicle Cost

The FFV feature comes standard on the vehicles shown in the table above. Since all models have this feature, there is no incremental cost to the consumer for this capability to operate the vehicle on E85.

Projection of Ethanol Vehicle Populations by 2005

FFVs that are designed for operation on E85 are already commercially available, as noted above. Thousands are currently on the road in California, and this is expected to continue as long as automakers offer the FFV feature as standard equipment on popular models. Future developments to market more advanced ethanol-fueled vehicles are unknown. No major automobile or HDV manufacturers have announced plans to commercialize dedicated ethanol vehicles (E85 or E100) in California. Like methanol, ethanol can be used as a carrier of hydrogen for fuel cell vehicles (see section 3.2.1), although on-board reforming of ethanol presents greater technical challenges than methanol. Several manufacturers of reformer systems are working on "multi-fuel" reformers that include the capability to use ethanol. However, no information is available regarding any definitive plans by vehicle manufacturers to pursue this option on their fuel cell vehicles. In sum, the number of E85 FFVs is irrelevant to potential ethanol infrastructure development unless E85 is actually used, which to date has not been the case in California. Prospects appear low for dedicated ethanol vehicles to be commercially available in California by 2005.

3.2 Longer-Term Fuel / Vehicle Technologies

The California Clean Fuel Infrastructure Development Plan acknowledges that certain not-yet-commercial fuel and vehicle technologies have significant potential to displace petroleum fuels within the next decade, and provide emissions reductions. Among the options included here are advanced internal combustion engine vehicles and fuel cell vehicles using neat methanol (M100) or hydrogen. In particular, fuel cells[38] using methanol and hydrogen fuel are expected to play roles in meeting California's needs for zero- or near-zero-emission vehicles. However, these fuels can also work well in advanced internal combustion engine vehicles, while providing extremely low emissions. The following sections focus on the use of methanol and hydrogen in fuel cell vehicles, but the same infrastructure issues and barriers apply for ICE vehicles using these fuels.

[37] National Renewable Energy Laboratory, Alternative Fuels Data Center website (http://www.afdc.nrel.gov/altfuel/eth_general.html).

[38] The leading fuel cell technology for automotive propulsion is the Proton Exchange Membrane Fuel Cell, to which this document refers.

Fuel cells offer the advantages of batteries because they derive power from electrochemical reactions (i.e., no combustion) and utilize electric propulsion systems. Like engines, fuel cells generate power from an on-board fuel that can be rapidly replenished at a fueling station. Thus, they can deliver equivalent range and refueling time. Fuel cells can operate on several fuels, including gasoline, methanol, ethanol and pure hydrogen. Several auto manufacturers have announced plans to sell fuel cell vehicles by 2004, and prototype passenger vehicles are now being tested. However, significant technical and cost hurdles must be overcome before these vehicles are likely to become commercially viable, and displace significant numbers of conventional vehicles. Perhaps the biggest hurdle pertains to fuel logistics and infrastructure.

Recently, the Air Resources Board, the Energy Commission and the South Coast Air Quality Management District joined with a collaboration of auto manufacturers, fuel providers, and fuel cell developers to form the California Fuel Cell Partnership. This Partnership has announced plans to demonstrate both LDVs and HDVs with fuel cell engines. Among the first vehicles that will be deployed are transit buses powered by fuel cells (similar to those that are already carrying passengers in public demonstration programs in several North American cities). Based on these activities, it appears likely that fuel cells will be deployed in heavy-duty vehicle applications first, for all the factors previously discussed that make this sector conducive to early adoption of advanced technologies and new fuels. The following sections describe the commercial status and prospects for fuel cell vehicles fueled by methanol and hydrogen.

3.2.1 Methanol Fuel Cell Vehicles

Technological Maturity

For much of the late 1980s and early 1990s, many light-duty FFVs powered by M85 were deployed in California. Over the same approximate time period, heavy-duty engines fueled by M100 were used to power many transit buses in California, as well as numerous heavy-duty trucks. At its peak use, methanol was sold at more than 100 public and private facilities around the state, and methanol-fueled vehicles accumulated tens of millions of miles.[39] However, methanol does not play a significant role in California today as an alternative transportation fuel.

This may change because methanol is an excellent carrier of hydrogen for use in fuel cells. Several automakers indicate they will design their fuel cell vehicles to run on methanol. Among those that have methanol fuel cell programs for light-duty vehicles are Daimler-Chysler, Toyota, Honda, GM, Ford, Opel, and Nissan. Other programs are focusing on methanol fuel cells for transit bus applications. On the nearest horizon are systems that use on-board reforming of methanol to supply hydrogen to the fuel cell engine. For the longer term, “direct methanol” fuel cells are being developed that will offer the advantages of using a liquid fuel without the need for onboard reforming.[40]

[39] According to the California Energy Commission, http://www.energy.ca.gov/afvs/m85/index.html.

[40] On-board reforming increases costs, lowers vehicle efficiency and results in tailpipe emissions (albeit, at very low levels).

Projected Methanol Vehicle Populations by 2010

Little detailed information is currently available about the methanol-fueled fuel cell vehicles that are likely to be deployed in California, and when they will truly be ready for commercialization. It is expected that additional information will be released in the coming year, through the California Fuel Cell Partnership.

3.2.2 Hydrogen Fuel Cell Vehicles

Technological Maturity

As noted above, several manufacturers have announced plans to produce fuel cell vehicles that run on methanol or gasoline by the 2004 time frame. However, many of those same manufacturers are equally engaged in programs to develop and eventually commercialize "direct-hydrogen" fuel cell vehicles.[41] Such vehicles have potential to provide the highest efficiency and fuel economy of any currently known, practicable propulsion technology – while delivering zero-emissions and strong multi-media environmental benefits. Hydrogen is therefore expected to be the long-term fuel for fuel cell vehicles. On strictly a demonstration scale, in certain niche applications such as transit buses, direct-hydrogen fuel cell vehicles are already displacing conventionally fueled vehicles (see Table 21). Much of this work is being sponsored by the California Fuel Cell Partnership, of which the Energy Commission is a member.

As the Fuel Cell Partnership recognizes, both heavy-duty (transit) and light-duty fuel cell vehicles will probably be deployed initially in fleet applications, to accommodate higher vehicle costs as well as fueling, operation, and maintenance requirements. A goal of the Partnership is to deploy up to 50 light-duty fuel cell vehicles in California by the end of 2001. Most or all of these demonstration vehicles will be fueled by compressed hydrogen. For heavy-duty applications, hydrogen-fueled buses will be deployed initially at progressive transit agencies already having CNG fueling facilities that can make the transition to hydrogen. As of early 2001, Sunline Transit in Palm Desert has taken delivery of one direct-hydrogen bus, manufactured by New Flyer with a "Phase 4" XCELLSiS fuel cell engine. This is the only such bus currently available in the world,[42] although it is not yet being operated in revenue service. By 2003, larger transit districts (>200 buses) that have opted for the "diesel path" under CARB's transit bus fleet regulation must begin demonstrating three of these Zero-Emission Buses (ZEBs). By 2008, they will be required to begin purchasing ZEBs (two years sooner than if they had selected the "alternative fuels" path).

To date, Sunline Transit has been California's most aggressive agency to demonstrate hydrogen buses, but AC Transit may be the first to deploy them in revenue service. Having chosen the "diesel path" for compliance with CARB's transit bus fleet rule, AC Transit is "marshaling resources" to deploy at least 12 fuel-cell powered buses in 2003, and hopes to

[41] For example, Ballard Power's affiliate, XCELLSiS indicates that by 2004 its fuel cell engine system will be "ready for serial production" for both automobile and urban transit bus applications. on March 26, 2001 Ballard announced that it will supply Mark 900 stacks for XCELLSiS fuel cell engines that will be integrated into 30 Daimler Chrysler buses. These will reportedly be deployed in European cities by 2003. However, this may be too optimistic for the U.S. market.

[42] Martin Rogers, XCELLSiS, personal communication to Jon Leonard, April 12, 2001.

operate "a largely zero-emission fleet" by the end of this decade.[43] To date, AC Transit has already procured government grants amounting to more than $13 million, and by 2002 it expects to have at least two fuel cell buses operational as well as a state-of-the-art fueling and maintenance facility. Sunline Transit, Santa Clara Valley Transit, and at least one other transit agency are expected to operate buses from the initial 20-bus procurement. DOE's National Renewable Energy Laboratory is working with the University of California, Davis to assist these agencies in the transition to hydrogen, and provide data collection activities.

Demonstrations aside, achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production and infrastructure investments of very large proportions. On the vehicle side alone, major efforts are needed to develop affordable and workable on-board hydrogen storage systems. Even as fuel cell vehicles begin to achieve commercial status, much work needs to be done to educate permitting officials, the general public, and business communities about hydrogen fuel and fuel cell technologies. According to "early adopters" of hydrogen-fueled vehicles and fueling stations, the largest barrier may be the current lack of hydrogen-specific codes and standards that provide for safe use of this unique fuel without being overly burdensome or costly to meet.[44]

While the magnitude of the task is large, the planning process for direct-hydrogen fuel cell vehicles and hydrogen fueling stations is underway today.[45] Hydrogen is therefore expected to play a gradually growing role in the California Clean Fuels Infrastructure Development Plan over the next decade.

Table 21. Examples of hydrogen fuel cell vehicles under development

Vehicle OEM(s)	Fuel Cell OEM	Vehicle Type	Notes / Plans for Commercialization
To be determined	International Fuel Cells	Passenger Car	Under demonstration
Daimler-Chrysler	Ballard / XCELLSiS	Passenger Car	NECAR 2, NECAR 4 (Mercedes A-class)
Ford	Ballard / XCELLSiS	Passenger Car, SUV	Timeframe unknown
New Flyer	Ballard/ XCELLSiS	Transit Bus	1 now being demonstrated at Sunline Transit in Palm Desert
Honda	Celanese Ventures	Passenger Car	Timeframe unknown
Hyundai / Impco	Ballard/ XCELLSiS	SUV	Demonstration phase

Vehicle Range and Fuel Economy

As noted previously, internal combustion engine (ICE) vehicles that use compressed or liquefied natural gas currently deliver significantly reduced range compared to similar conventional vehicles. Fuel cell engines operate more efficiently than internal combustion

[43] AC Transit website (http://www.ACTransit.org).

[44] For example, this is a top concern of Sunline Transit Agency's management concerning expansion of its hydrogen fuel cell bus program.

[45] For example, Arthur D. Little and UC-Davis are working with the National Renewable Energy Laboratory to assess the infrastructure needs of transit districts that will demonstrate a few hydrogen-fueled demonstration buses in 2003, and begin purchasing them in 2008.

engines (ICEs), enabling fuel cell vehicles to get more miles from a given volume of the same fuel. Direct-hydrogen fuel cell vehicles are especially efficient, because no on-board fuel reformation process is needed. Also, electric drive systems offer significant efficiency gains over conventional drive systems, as demonstrated by the Toyota Prius and Honda Insight hybrid EVs. Putting these factors together, the improved energy-conversion efficiency of fuel cell vehicles can have a "dramatic impact" on reducing the weight and size of the fuel storage system."[46] A direct result is that fuel cell vehicles can provide greater vehicle range than would be available from an ICE vehicle using hydrogen. On the negative side, any type of hydrogen-fueled vehicle faces the range constraint of reduced energy content per volume and/or mass of fuel (depending on which form of on-board hydrogen storage is used). Determining if direct-hydrogen fuel cell vehicles can achieve near-equivalent range to conventional vehicles will require real-world operating experience. It is expected that such information will begin to emerge in late 2001 from Sunline Transit's experience with California's first fuel cell bus. Also, in mid 2001, Quantum Technologies (an Impco subsidiary) introduced advanced hydrogen storage technology for vehicle applications.

Vehicle Cost

Direct-hydrogen fuel cell vehicles today are generally built by converting an existing LDV or HDV. This includes adding on-board storage of hydrogen and replacing the conventional engine and transmission with a fuel cell engine and electric-drive system. Fuel storage is a particularly challenging and costly issue for hydrogen vehicles. While compressed hydrogen is typically used in today's prototype vehicles, at least four additional methods are being considered: 1) liquefied hydrogen, 2) selected metal hydrides, 3) refrigerated superactive carbon, and 4) carbon or graphite nanostructure[47] technology.

Some manufacturers are building fuel cell electric drive systems that are powered solely by a fuel cell engine, while others are building hybrid drive systems that include a battery pack or some other source for peak power requirements. In part, this choice depends on what vehicle application is desired, e.g., passenger cars or a transit buses. Regardless, fuel cell vehicles are virtually "hand built" today and their current incremental cost significantly exceeds that of any other mainstream clean-vehicle alternative. With continued progress in building low-cost, high-power-density fuel cell engines, production costs for fuel cell vehicles can be dramatically reduced. However, a number of major challenges remain before hydrogen fuel cell vehicles can become cost comparable with conventional vehicles.[48]

Projected Hydrogen Vehicle Populations by 2010

Given the current barriers and uncertainty on how manufacturers will meet certain regulatory drivers, it's difficult to assess the number of fuel cell vehicles that will actually be on the

[46] International Academy of Science, Hydrogen Tech Paper #89001, "Hydrogen Fuel Cell Vehicles, " 1997, by Dr. Roger E. Billings.

[47] Associate Professor J. Lin, National University of Singapore, New Discoveries with Hydrogen Storage for Fuel Cell Application, Fuel Cell Technology Conference-Asia, December 7, 1999; Eldridge, Ken, Nanotubes for Hydrogen Storage, Internet Web site: http://www.pa.msu.edu/cmp/csc/NANOTUBE-99/puzzles/4.4.html, May 1999.

[48] Challenges include cost and supply issues for precious metals and other materials making up membrane-electrode assemblies; the need for advanced, lower-cost hydrogen storage technology; tradeoffs associated with on-board air compression versus using ambient pressure stacks; and difficulties with delivery of constant power during transient operation.

road in California over the next 5 to 10 years. One such assessment was made in a document entitled *Blueprint for Hydrogen Fuel Infrastructure*, which included both high and low scenarios for vehicles powered by hydrogen fuel cells.[49] In one scenario, the *Blueprint* assumed that up to 10,000 vehicles will appear in the new vehicle market in 2003, driven by California's ZEV and ZEB regulations.[50] In a second scenario, the *Blueprint* assumed that only about 50 hydrogen fuel cell vehicles will be demonstrated over the next five years, through CARB's ZEB requirement and projects under the California Fuel Cell Partnership.

It appears that the *Blueprint's* second scenario is most likely to come to fruition. Based on the best available information as of mid 2001, it appears that no more than 25 fuel cell buses will be deployed in California by 2005,[51] with perhaps an equivalent number of light-duty fuel cell vehicles. In 2008, CARB's transit bus fleet rule requires that California's large transit districts on the diesel path begin phasing in ZEBs. Large districts on the alternative fuel path must do the same in 2010. While there is considerable uncertainty, it is anticipated that this will result in up to 20 more hydrogen fuel cell buses deployed over the three years from 2008 to 2010.[52]

Over the longer term (20 years or more), prospects look promising to significantly displace petroleum fuels in California through use of hydrogen vehicles. There is little consensus on the exact timeframe, but many public- and private-sector experts believe that direct-hydrogen fuel cell vehicles will gradually replace internal combustion engine vehicles as the predominant mode of transportation in metropolitan areas throughout California and the United States.

[49] *Blueprint for Hydrogen Fuel Infrastructure* Development, Jim Ohi, National Renewable Energy Laboratory, based on October 1999 workshop cosponsored by US DOE, California Energy Commission, and the California Air Resources Board.

[50] After these numbers were developed, requirements for the ZEV program were changed by CARB that affect automakers' incentives to produce direct-hydrogen fuel cell vehicles.

[51] Ken Koyama, California Energy Commission, personal communication to Jon Leonard on 02/01/01.

[52] This assumes that there are 5 large transit districts (>200 buses), and each will need to procure an average of 8 buses per year, 15% of which will need to be ZEBs.

4. Status of the Clean Fuels Infrastructure in California

The numbers of stations that dispense a given clean fuel type, and the quantities of fuels dispensed, are directly correlated with the types and numbers of vehicles using the fuel. The previous section provided an overview of existing clean fuel vehicles in California, as well as those types expected to emerge over the next five years. This section assesses the commercial status of the fuels themselves and their corresponding infrastructure in California.

4.1 Natural Gas Supply, Demand and Price

Regardless of how it is stored onboard vehicles (CNG or LNG), the raw commodity of natural gas must be extracted or produced, transported to the end user's site (if not produced on site), and prepared for consumption. Two basic forms of natural gas are produced in California: "associated gas" and "non-associated gas." Associated gas is produced along with crude oil, while non-associated gas is not affiliated with oil fields. About 75% of the natural gas produced in California is associated gas. In 1999, total natural gas production in California averaged approximately 1.0 billion cubic feet per day. The average production in 2000 was approximately 920.5 million cubic feet per day – a decrease of about 11% compared to the previous year. The lowest year on record for natural gas production in California was 1996, which averaged a production rate of approximately 800 million cubic feet per day. [53]

Today, California's consumption accounts for about 10% of the total natural gas consumption in the United States. Only about 16% of this demand for natural gas is currently met by the in-state production levels noted above. On average, about 6 billion cubic feet per day of natural gas were consumed in California in 1999.[54] During months of peak consumption (i.e., the winter heating months), as much as 7.5 billion cubic feet per day can be consumed in California. The total amount of gas delivered to California consumers in 1999 was about 2,100 billion (2.1 trillion) cubic feet. Table 22 provides a breakdown of this by individual use sectors. It indicates that about half of California's natural gas deliveries in 1999 were for industrial applications (more than one trillion cubic feet), while only about 0.2% (3.3 million cubic feet) was used as a transportation fuel. Although the volume of natural gas delivered for vehicle applications was a small part of California's total consumption, more than half of the natural gas nationwide for this sector was consumed in California (see last column of Table 22). This is indicative of the leading role that California has played over the last decade towards "early adoption" of natural gas vehicles.

[53] California Department of Conservation: Division of Oil, Gas, and Geothermal Resources, 2000 Preliminary Report of California oil and Gas Production Statistics, January 2001, from website (http://www.consrv.ca.gov/dog/publications/whatsup.htm).

[54] Estimates for California's 1999 consumption ranges from 5.7 BCF/day (Energy Information Administration) to 6.1 BCF/day (California Energy Commission).

Table 22. 1999 Natural Gas Deliveries in California by Consumer Type

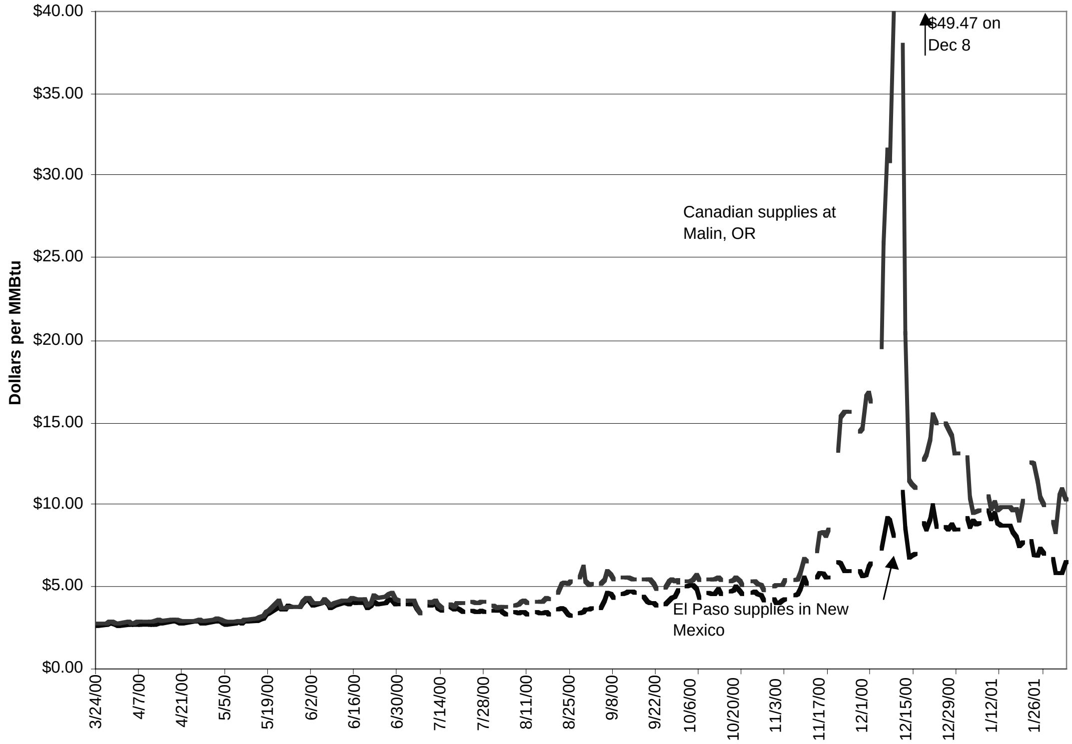
Consumer Sector / Application	Deliveries to Consumers (Billion Cubic Feet)	% of Total California Deliveries	% of National Consumption for Sector / Application
Industrial	1,109.4	53.5%	12.3%
Residential	568.5	27.5%	12.0%
Commercial	244.7	11.8%	8.0%
Electric Utilities	144.7	7.0%	4.7%
Transportation Fuel	0.3	0.2%	58.5%
Totals	**2,067.6**	**1%**	**10.4%**

Source: Energy Information Administration, Natural Gas Annual 1999, "California – Natural Gas 1999" p.100, from EIA website (http://www.eia.doe.gov/oil_gas/natural_gas/nat_frame.html)

To meet the shortfall of supply versus demand, which is roughly 1,850 billion cubic feet (BCF) per year, California annually imports about 1,200 BCF from other western states and 650 BCF from Canada. Transport of most natural gas into California is accomplished by an interstate pipeline system with a capacity of about 7.1 billion cubic feet per day, or 2,600 BCF annually.[55] With so much of California's natural gas supply dependent on this pipeline system, capacity and operational issues are continually reviewed. In November 2000, an Energy Commission staff report found that "local constraints" in California's natural gas pipeline system can be problematic, but "the physical capacity of interstate pipelines appears adequate, when used in conjunction with in-state storage capability."[56]

[55]Information in this paragraph was obtained from various documents on the websites of the California Energy Commission (http://www.energy.ca.gov.gov/naturalgas) and Energy Information Administration (http://www.eia.doe.gov/oil_gas/natural_gas/nat_frame.html)

[56] California Energy Commission, "California Natural Gas Analysis and Issues," Staff Report P200-00-006, November 2000, from website (http://www.energy.ca.gov/naturalgas).



Source: Energy Information Administration, briefing for staff of the U.S. House of Representatives, 02/01/01

Figure 4-1. Natural gas spot prices, March '00 to January '01

Over the last decade, prices of natural gas to the consumer have been relatively low and stable. However, in the Summer of 2000, natural gas spot prices began significantly increasing, as shown in Figure 4-1. During late 2000 and early 2001, prices reached all-time highs exceeding $49.47 per MMBtu. As of March 2001, prices began to stabilize back down towards recent historical ranges between $5 and $8 per MMBtu. Among the contributing factors to higher natural gas prices were 1) cold weather, 2) high demand (especially from natural-gas-fueled electricity generators), 3) tight supply, 4) lack of recent supply development, 5) lack of alternatives to gas delivered through Topock, Arizona, 6) transport issues (e.g., pipeline limitations), and 7) low storage levels from slow rate of gas injection.[57,58,59]

Energy experts indicate that there may be further volatility and higher prices for natural gas over the next several years. In part, this is because demand for natural gas in California will

[57]Statement of Mark J. Mazur, Acting Administrator, Energy Information Administration, before the Committee on Commerce, Subcommittee on Energy and Power, U.S. House of Representatives, September 28, 2000.

[58] California Energy Commission, "Natural Gas Price Increases – Frequently Asked Questions," website (http://www.energy.ca.gov/naturalgas/natural_gas_faq.html), as of December 10, 2000.

[59] Applications to build new California pipeline capacity have been stepped up in recent months, and the US Federal Energy Regulatory Commission has pledged that it will act "as quickly as possible" to expedite approval of new pipelines (Oil & Gas Journal, March 2, 2001).

increase significantly to alleviate the current energy crisis. California already has more natural-gas-fired powerplants than any other state, and is now accelerating efforts to bring major additional electricity generating capacity on line to alleviate its current energy crisis. On February 8, 2001 emergency action was taken to expedite the review and permitting process of power generating facilities in California. An additional 20,000 megawatts will reportedly be brought online by July 2004, starting with 5,000 additional megawatts by July 2001 and 5,000 more megawatts by July 2002.[60] In late March 2001, the Energy Commission approved applications to build three new natural gas plants in central and southern California, bringing the total of new plants that have been approved since mid 1999 to 13 (8,405 MW of added power capacity).[61]

With efforts recently accelerated to add new natural-gas-fired electricity generation plants, applications to build new California pipeline capacity have also been stepped up. Several new pipelines serving California have recently been announced.[62] The US Federal Energy Regulatory Commission has pledged that it will act "as quickly as possible" to expedite approval of new pipelines.[63] California's two biggest gas utilities, Southern California Gas and Pacific Gas & Electric, have acknowledged the potential for natural gas supply constraints and resulting higher prices. While both utilities forecast that natural gas prices for electricity generation will remain relatively high for the next two to three years, company representatives have predicted that prices will re-stabilize in mid 2003 to a range between $2 and $3 per MMBtu.[64]

Prices at the pump for gasoline and diesel fuels also reached unusually high levels in 2000 (see Figure 4-2 and Figure 4-3). According to the Energy Information Administration, world oil prices reached a daily peak of $37 per barrel in 2000 – the highest rate since the Persian Gulf War of 1990-1991. Oil prices have since stabilized in the range of $25 to $28 per barrel, at which EIA projects they will remain over the next several years.[65] However, as of Spring 2001, the price of regular gasoline reached well over $2.00 per gallon, and could approach $3.00 per gallon due to limited refining capacity. Similar price volatility is expected for diesel fuel.

[60] Source: California Air Resources Board, press release from website (http://www.arb.ca.gov/energy/energy.htm).

[61] Governor Gray Davis, Press Release: "Approved Power Plants Will Add Over 2,000 Megawatts," March 22, 2001.

[62] Source: The Electricity Daily: "Calif. Utilities Spurned Pipeline Projects", Vol. 16, No. 96, May 18, 2001.

[63] Oil & Gas Journal, March 2, 2001.

[64] Input from representatives of The Gas Company and PG&E at LNG strategy meeting held at Arthur D. Little on February 12, 2001, Fullerton California.

[65] Energy Information Administration, Press Release: "Strong Growth in World Energy Demand Projected," 3/28/01, from website (http://www.eia.doe.gov/neic/press/press176.html).

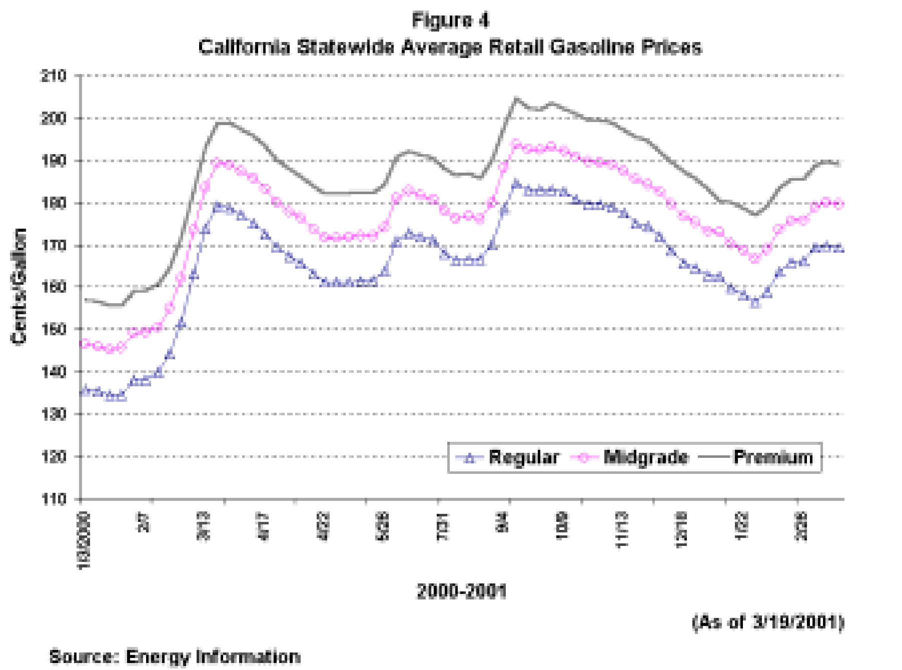


Figure 4-2. Average retail gasoline prices in California, 2000-2001

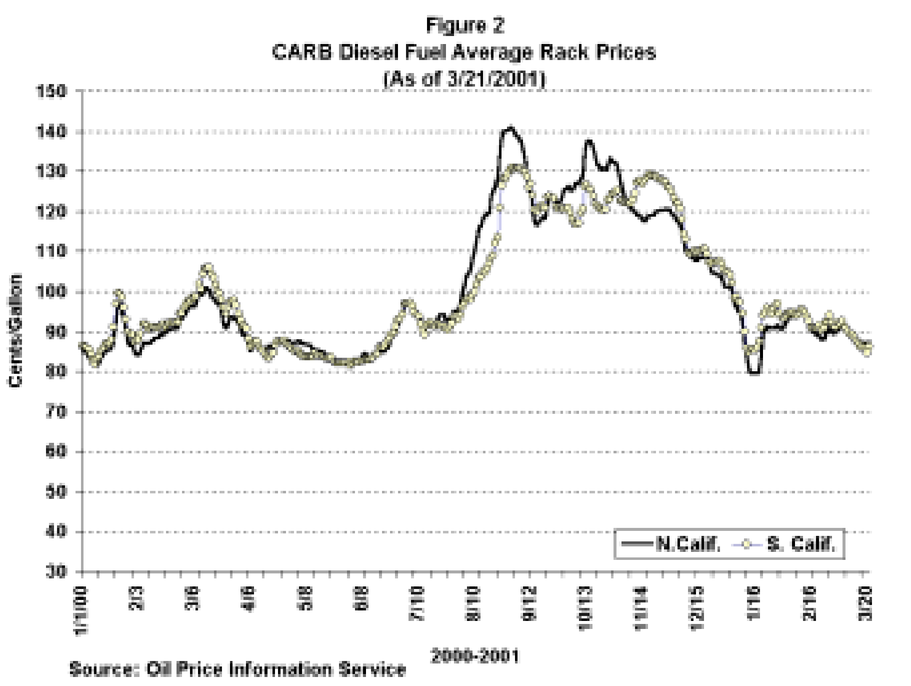
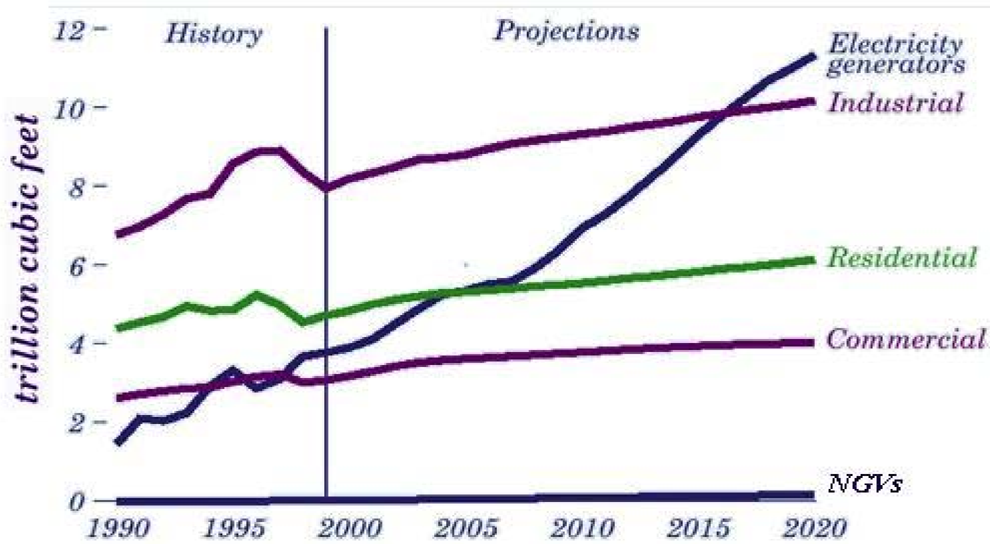


Figure 4-3. Average rack prices for California diesel fuel, 2000-2001

Longer-Term Outlook

Nationwide, natural gas consumption is expected to grow by about 60% over the next two decades, from 21.4 trillion cubic feet (TCF) in 1999 to 34 TCF in 2020.[66] Rising demand by electricity generators is expected to account for more than 50% of the increase, eventually surpassing industrial uses as the largest consumer of natural gas. Demand for natural gas as a vehicle fuel is also expected to grow significantly by 2020, but the federal government projects that it will remain a fractional percentage of total use in the United States (see Figure 4-4).



Source: U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook 2001

Figure 4-4. Existing and Projected Growth in NG Consumption for the U.S., by Sector

For the longer term as well as the near term, California's accelerated efforts to build new natural- gas-fired electricity generation plants will lead to significant increases in the statewide demand for natural gas. The Energy Commission has forecasted that the State's total natural gas use will increase from about 6.4 BCF per day in 2000 to 7.5 BCF per day in 2010 – with most of the increase resulting from new electricity generation facilities.[67] This has led to concerns that longer-term supplies of natural gas in California – most of which must be imported via aging pipeline systems – will be insufficient to meet the state's growing demand. Related to this is the concern that high demand and constrained supply will continue to keep natural gas prices high, well above historical trends.

[66] 34 TCF for 2020 is the mid estimate provided by the Energy Information Administration, Annual Energy Outlook 2001, Report #DOE/EIA-0383(2001), December 22, 2000, from EIA website (http://www.eia.doe.gov).

[67] California Energy Commission, "California Natural Gas Analysis and Issues," Staff Report P200-00-006, November 2000, from website (http://www.energy.ca.gov/naturalgas).

Recent reports from the Energy Commission as well as federal agencies have addressed these issues. Commission staff concluded that "the substantial North American natural gas resources can meet the nation's demand for at least the next 50 years, at current consumption levels." The federal Energy Information Administration also concluded that natural gas is an abundant resource, and the supply by 2020 will be adequate to meet nationwide demand. EIA reports indicate that technological improvements will help increase production and restore reserve levels to historical highs. EIA models have predicted that consumer prices for natural gas in "all end-use sectors" will be "higher in 2020," but prices in the residential and transportation sectors are expected to remain within 5% of 1999 levels. Short-term prices are likely to remain volatile, but EIA expects them to moderate in 2001 and stabilize back in the range of $3 to $4 per MMBtu.[68]

Implications of Natural Gas Market Turmoil to CNG and LNG Infrastructure Development

In summary, there is significant turmoil in current natural gas markets, but the long-term outlooks for supply and price may be favorable. Recent analyses by the Energy Commission have concluded that 1) natural gas resources available to California (in state production and imported gas) are adequate to meet demand for at least 50 years, and 2) current high prices "are a short-term phenomenon."[69] A key federal agency has made similar projections. For the purposes of this Clean Fuels Market Assessment, it is reasonable to assume that sufficient supply will be available to meet the relatively small volumes of natural gas needed in the transportation sector over the next two decades. However, this situation is dynamic and subject to change, increasing the normal level of risk associated with funding natural gas fueling stations.

4.2 Natural Gas Fueling Stations

As previously described, natural gas vehicles are commercially available from numerous major vehicle and engine manufactures. Natural gas is commonly stored onboard vehicles in two forms: compressed (CNG) and liquefied (LNG). CNG has been the dominant type of natural gas vehicle sold in the United States, and is likely to remain the leader for light and medium-duty applications. However, LNG has become increasingly prevalent as a fuel for transit buses, and some transit properties are now ordering LNG versions of natural gas buses instead of CNG versions. Recent regulatory actions by CARB and the South Coast Air Quality Management District are creating additional pressures for manufacturers and end-users alike to deploy alternative fueled HDVs (see Appendix A), and LNG is proving to be a promising fuel for such applications. This expanded use of LNG in heavy-duty vehicle applications has resulted in stepped-up activity to fund and build new LNG stations.

Yet another development is the emergence of the "L/CNG" station as a viable alternative to building CNG stations. These specialized stations can produce CNG by pumping LNG[70] to high pressure, then vaporizing and dispensing it -- avoiding the high costs associated with

[68] Natural Gas Market: Status and Outlook, presentation by Barbara Mariner-Volpe of the Energy Information Administration, January 24, 2001, from EIA website (http://www.eia.doe.gov/pub/oil_gas/natural_gas/presentations).

[69] California Energy Commission, "California Natural Gas Analysis and Issues," Staff Report P200-00-006, November 2000, from website (http://www.energy.ca.gov/naturalgas). See Figures 6 and 7 in the report.

[70] For more information regarding LNG supply and LNG infrastructure see section 4.2.2 "LNG Fuel and Stations"

gas compression at conventional CNG stations. L/CNG stations provide an integrated NGV strategy for fleets because light-duty CNG vehicles and heavy-duty LNG vehicles can be fueled at the same facility.

Today a mix of CNG, LNG and L/CNG stations is beginning to emerge in California as a solid, potentially sustainable infrastructure. Each of these natural gas station types is discussed further below.

4.2.1 CNG Stations

Number of Stations

As of early 2001, there are approximately 240 CNG stations operating in California. More than half of these stations have access that is limited to the immediate on-site fleet, or perhaps select NGV users by special arrangement. Approximately 106 stations offer full or partial public access. Table 23 provides an overview of these stations categorized by the owner / operator, the primary types of vehicles fueled at the station, and the estimated average throughput that exists at a "typical" station today.

Table 23. Overview of Existing CNG Stations in California, by Owner / Operator

	SoCal Gas, SDG&E and Long Beach Gas	Pacific Gas & Electric	Trillium USA	FleetStar, Inc.	Pickens Fuel Corporation	Pinnacle CNG Company
Existing # of CNG Stations	131	35	5	9	15	5
Primary Type of Vehicle Fueled	LDVs, MDVs	LDVs, MDVs	Transit Buses, HDVs	LDVs, MDVs	MDVs, HDVs, Transit Buses	MDVs, HDVs
Average Throughput (GGE*/month)	8,000	5,000	12,000 (standard), 300,000 (transit)	3,000	20,000	15,600

Source: Fueling Infrastructure Survey, conducted mid 2000, California Energy Commission

*GGE = gasoline gallon equivalent. 1 GGE = 125 scf of natural gas, or 1.25 therms.

Existing and Needed Fuel Throughput

"Throughput" refers to the volume of fuel dispensed over a given period of time at a fueling station. Throughput at each CNG station is a function of 1) how many natural gas vehicles are fueled, 2) how frequently they fuel, and 3) the volume of CNG dispensed during each fueling event. Thus, the highest throughput stations are those that serve large numbers of HDVs (which hold the most CNG and have the highest fuel consumption rates) on a daily basis. Currently, this description most consistently fits major transit bus operations with CNG station capacities exceeding 1000 cubic feet per minute.   According to input from one

TAG[71] member, natural gas throughput at a large transit district can be as high as 300,000 gasoline gallon equivalents (GGE) per month (see table above).

Stations that dispense medium volumes of CNG tend to be anchored by government or quasi-government facilities such as military bases, small transit properties, and educational institutions. The majority of natural gas vehicles operated by these entities are typically medium- and heavy-duty types such as school buses, shuttle buses, meter trucks, cargo vans, large pickup trucks, package vans, step vans, flat-bed trucks, and service-body trucks.

Ironically, the lowest-throughput CNG stations today are those that are more optimized for public access and designed to be as user-friendly as possible. These are the public stations that are not usually affiliated with anchor fleets, and tend to be located at normal gasoline stations on busy thoroughfares.

In the post-deregulation era, the CNG business is increasingly shifting from gas utilities to private-sector "turnkey" providers. One result is that low-throughput CNG stations are becoming candidates for closing, while new large-throughput stations are being built for heavy-duty fleets. To further assess this trend, the following four turnkey CNG providers were surveyed in early 2000: 1) Trillium USA, 2) Fleetstar, 3) Pinnacle CNG Systems, LLC; and 4) Pickens Fuel Corporation. Each has a strong vested interest in California's natural gas vehicle fueling market, and is represented on the TAG. These companies were asked to briefly characterize their involvement in the natural gas fuel business, and how they structure arrangements with CNG users. The following summarizes their responses.

- All four companies seek "take or pay" fuel contracts in which the customer will guarantee a minimum gas throughput ranging from 150,000 to 260,000 gasoline-gallon equivalents per year (12,500 to 22,000 GGE / month). Such fuel usage typically requires a large "anchor" fleet of natural gas vehicles.
- They typically require a minimum contract commitment of five years.
- Three out of four indicated that HDVs should be the targeted vehicle type for natural gas use; one indicated interest in serving MDVs on an equal basis.

In mid 2000, these same four companies as well as several California utilities and natural gas proponents (all TAG members) were sent new, more detailed surveys. Figure 4-5 summarizes input from these TAG members about the average throughput at CNG stations today, and the throughput that they believe is necessary to invest capital in a new CNG station. It is notable that the three turnkey companies most involved in the California CNG infrastructure today – Trillium USA, Pickens Fuel Corporation, and Pinnacle CNG – operate the stations with the highest average throughput. These companies require at least 13,000 GGEs per month of gas consumption before they are willing to invest capital in a new station.

[71] For a description and additional information on the TAG please see section 2.2 "Technical Advisory Group"

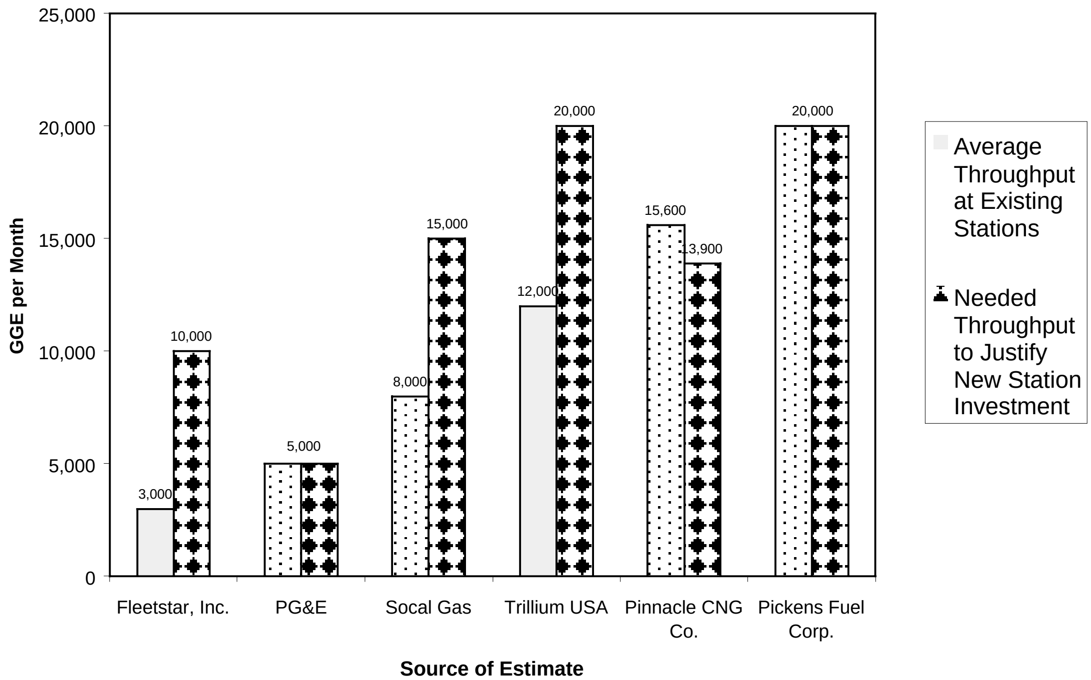


Figure 4-5. CNG throughput estimates from TAG members

A number of important dynamics are at work regarding these critical issues of CNG station access, size, throughput, and other factors. These dynamics will shape the future expansion of CNG stations in California, because effectively gas utilities will no longer be in the business of building, owning, or maintaining CNG stations (except possibly stations for their own vehicles). Consequently, stations that can't deliver high fuel throughput and attract major anchor fleets are likely to be candidates for closure.

As an example of these dynamics at work, in early 2000 Shell Oil Company reportedly made the decision to discontinue selling CNG at its three stations in San Diego County. However, all three CNG stations remain operational as of early 2001,[72] and Shell was considering allowing a third party to purchase the CNG station components, enabling the stations to remain open indefinitely.[73] However, it is unlikely that any private company can afford to take on responsibility for the stations unless it has a plan to significantly increase fuel throughput at these stations. Also, major new investments may be needed to keep such stations open and viable. One possible explanation of why Shell continues to operate these unprofitable stations is that a major auto manufacturer reportedly organized a "grass roots"

[72] Arthur D. Little staff called all three stations on August 4, 2000 and again on March 6, 2001. Each was still selling CNG.

[73] Personal communication from the Escondido Shell station manager to Jon Leonard, August 4, 2000. Corroborated by the California Natural Gas Vehicle Coalition website at http:\\www.califngv.org.

effort to keep CNG available to individuals and companies operating its NGVs in San Diego County.[74]

Current Price of CNG

Figure 4-6 shows Southern California Gas Company's commodity cost[75] for natural gas over the last three years, and the price that it has charged for CNG at its public stations during that same time period. It shows that the natural gas commodity and the price of CNG were both stable until mid 2000, with the retail price being about $1.00 per gasoline gallon equivalent (GGE, or 1.25 therms of natural gas). However, from May 2000 to December 2000, the price at the pump increased to as high as $1.67 per GGE.

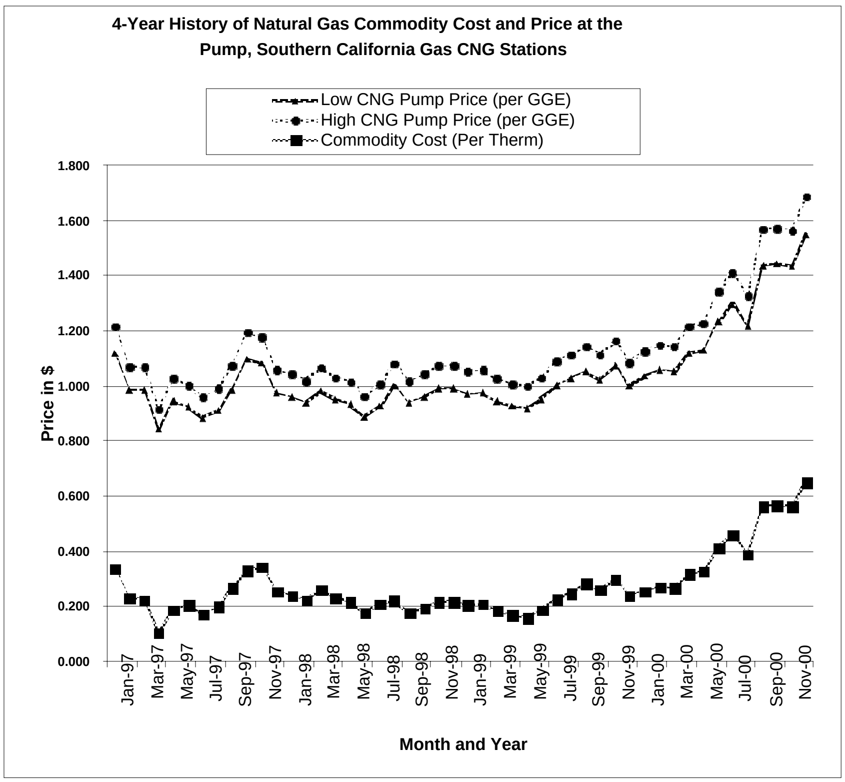


Figure 4-6. The Gas Company's commodity cost and price of CNG, 1997-2000.

Figure 4-7 shows the average price of CNG for December 2000 at 15 of The Gas Company's public access CNG stations. After this data was provided, the price of CNG has decreased off its December 2000 peak. As of April 2001, a typical price in Southern California is $1.55 to $1.60 per GGE.

The Gas Company's amortized cost for providing CNG to its customers breaks down as follows: 51.1% for core gas procurement, 27.4% for gas compression, 8.7% for

[74] Comments (speaker unknown) at the EPA Workshop on AFV Infrastructure, Clean Cities 2000, held in San Diego, May 2000.

[75] Commodity Cost = (Pump Price - Compression Costs - Transport Costs - Taxes/Fees)

interstate/intrastate transportation, and the remaining 12.8% for various taxes. Gas compression costs refer to the fully amortized costs of building, owning, operating and maintaining CNG fueling stations. These various types of costs are further discussed below.

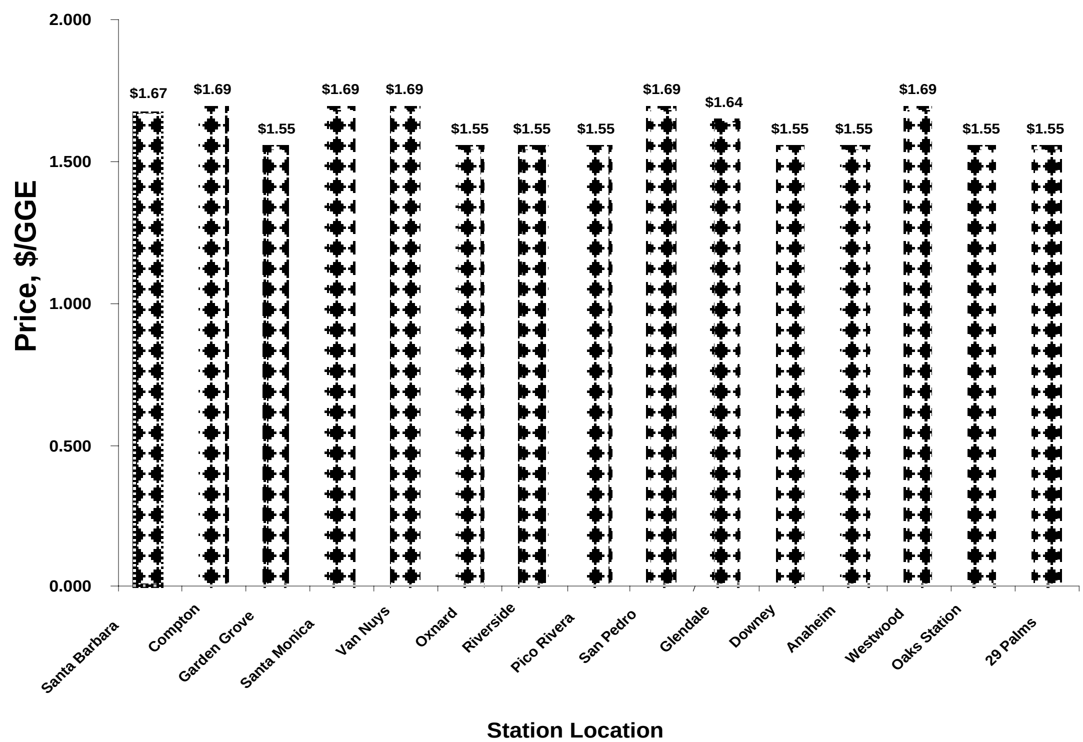
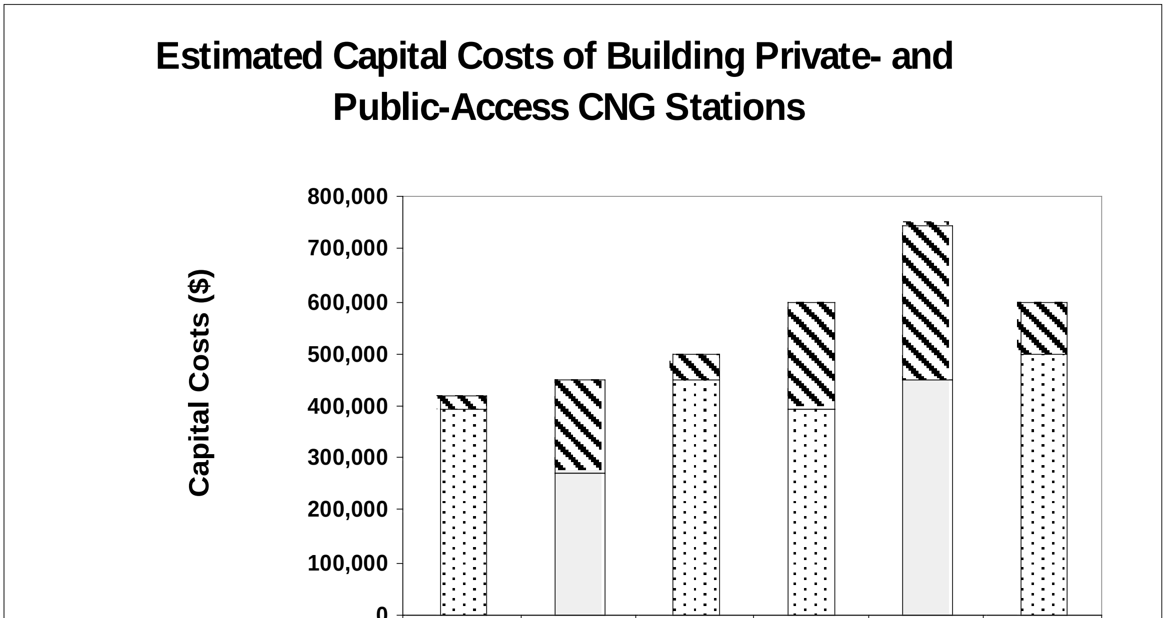


Figure 4-7. December 2000 CNG prices at 15 public access CNG stations

Station Capital Costs

High throughput is vitally important because the current high costs of CNG stations make it difficult for private industry to achieve a reasonable return on investment. This is a key barrier to wider deployment of CNG stations nationwide. As Figure 4-8 shows, fast fill systems of mainstream size (300 to 400 scfm) can cost $500,000, and public-access stations are significantly more expensive than private-access versions. The capital costs of CNG stations for large transit bus fleets can reach several million dollars.



	Pinnacle CNG Co.	Socal Gas Co.	Trillium USA	Cal NGV Coalition	PG&E	Pickens Fuel Corp.
Minimum Incremental Cost of Public Access Station	$25,000	$175,000	$50,000	$200,000	$300,000	$100,000
Capital Cost of Private-Access Station	395,000	275,000	450,000	400,000	450,000	500,000

Source: survey input from TAG members

Figure 4-8. Estimated costs to build CNG stations (approx. 300 to 400 scfm)

For these reasons, private-sector CNG providers primarily seek contracts with fleets that can consume very high volumes of fuel over a guaranteed period of multiple years (see below).

Station Operation, Maintenance and Training Costs

High operation and maintenance costs (including personnel training) are also major contributors to the relatively high life-cycle costs for CNG stations. Operational costs can be especially hard on user fleets because they are often higher than expected, with insufficient budgets to cover these expenses. Virtually all CNG station components require preventative maintenance on a regular basis to maintain station reliability. The station operator must either pay on-site staff to perform the maintenance, or pay for a contractor's services. Either case can be very expensive.

As a result, today's "turnkey" CNG providers essentially sell natural gas compression services to their customers. These fuel providers are willing to manage all aspects of a CNG facility's installation, operation, and maintenance, in exchange for an agreement by the customer to purchase a minimum throughput of fuel for a set period of time. Increasingly, fleets with very large throughputs of CNG fuel are executing agreements with these turnkey companies. For example, the Los Angeles County Metropolitan Transit Authority (LACMTA) has executed a 10-year capital lease agreement with Trillium USA, under which

Trillium built, owns and maintains two new CNG fueling stations on LACMTA property. After ten years LACMTA will reportedly purchase the Trillium USA CNG facilities for $1. For a 200-bus CNG fueling station, it is estimated that this type of contract can offer a 15% cost savings over ten years compared to a large transit district purchasing and operating its own CNG stations.[76]

Trillium USA's capital lease agreement with LACMTA was the first of its kind for a transit district in California. These types of agreements may represent the future, but currently they are available only to fleets buying high volumes of fuel (approximately 15,000 gasoline gallon equivalents per month). This equates to approximately 25 heavy-duty CNG vehicles being operated about 100 miles per day, 30 days per month.

Public Access: Hours and Accommodations

CNG stations equipped with the most sophisticated card lock systems -- networked card readers -- utilize a variety of payment cards and software. These systems may be more sophisticated than necessary for private stations but are generally considered essential for public-access stations. Before fueling at most public-access stations in California today, it is necessary to establish separate CNG accounts with the operator(s). Each site can vary in their hours of access, equipment, payment method, and on-site assistance. As Table 24 shows, it would require eight or nine different account cards to access all of the public CNG stations in California.[77] In Arizona, where currently at least four fuel-purchase cards are used, the problem is being addressed with a new requirement: all stations funded by government grants must install a card reader system that is compatible with Visa or Mastercard.[78] In some cases dual cards are used-one for access control and the second for verification of payment.

Table 24. Point-of-sale payment options at California's public-access CNG stations

Payment Option	Number of Stations Accepting (as of mid 2001)	% of Public Access CNG Stations in California That Use Payment Option
SoCalGas Card	38	36.2%
PG&E Card	27	25.7%
SDG&E Card	8	7.6%
Long Beach Gas Card	2	1.9%
Oil Company, Major CC or Cash	7	6.7%
FleetStar or CFN Card	8	7.6%
Pinnacle Card	5	4.8%
Pickens Fuel Corp Card	1	1.0%
Trillium USA Card	1	1.0%
"By Arrangement"	6	5.7%
"Any California CNG Card"	2	1.9%
Totals	**105**	**100.0%**

Source: California NGV Coalition website (http://www.califngv.org), list of CNG stations

[76] Based on private communications with Jan Hull of Trillium USA, and ADLittle's ongoing work to assess the costs of CNG infrastructure.

[77] California Natural Gas Vehicle Coalition website, *Fueling Stations Directory*.

[78] GRI Final Report, CNG Transit Fueling Station Handbook.

To a limited extent, government and industry representatives have already worked together to address this barrier. However, there is a consensus in the industry that greater efforts are needed to establish a single network for user-friendly and affordable point-of-sale payment options. Table 25 lists the existing and needed efforts in these areas, according to members of the TAG. Recently, the Energy Commission joined forces with the National Renewable Energy Laboratory, the South Coast Air Quality Management District (SCAQMD), natural gas retailers, and the card reader industry to develop an open architecture for card reader systems that will help expand and streamline the use of natural gas vehicles (as well as other AFV types).

Table 25. Summary of TAG input on existing and needed CNG payment RD&D

Source	Current Point-of Sale Options	Issues and/or RD&D Needs
Pickens Fuel Corporation	EJ Ward and Multi Force (California), Autogas (Arizona)	♦ Investigating user-friendly payment, i.e., MasterCard and Visa accessibility. Demonstrating “beta” station in Los Angeles with Multi Force ♦ Lack of reliable card readers is the “weakest link” in stations
Trillium USA	Autogas, EJ Ward, Visa, MasterCard	♦ CNG stations must be unattended for cost reasons ♦ Potential conflicts exist with UBC operator training requirements, which would be detrimental to widespread use
FleetStar	CFN	♦ Assurance of user training ♦ Release of liability
The Gas Company	EJ Ward	♦ Need a debit or credit card or a ubiquitous fueling card ♦ Need special funding to replace all NG card systems and dispensers throughout the state (like gasoline).
PG&E	Tech 21	♦ Need dispensing system algorithm
Pinnacle	Pinnacle Card	♦ Need non-attended VDM ♦ Need RS232 plug in for vehicle information and authorization
California NGV Coalition	CFN, EJ Ward, Autogas, Gasboy, Tech 21	♦ Various cards are incompatible ♦ Very limited Voyager / Visa / cash capability at present ♦ Need fuel network development and demonstration

Source: surveys received from TAG members

Building Codes and Standards

There are a number of specific codes and standards that must be met when building and/or operating CNG stations. Input from TAG members on these requirements are summarized in Table 26. Of these various codes and standards, the Uniform Building Code and NFPA 52 are the highest tier, and all others are somewhat secondary.

Table 26. TAG member input on codes and standards for CNG stations

Gladstein & Associates	SoCal Gas, SDG&E and Long Beach Gas	Pacific Gas & Electric	Trillium USA	FleetStar, Inc.	Pickens Fuel Corporation	Pinnacle CNG Company	California NGV Coaltion
NFPA 52, CCR Title 8, Division 1, Chapter 4, Subchapter 1, *Unfired Pressure Vessel Safety Orders.,* NFPA 70	UBC, NFPA 52, NEC, ASME Standards, etc.	UBC, NFPA 52, NEC, UFC	UBC, NFPA 52	NFPA 52, local building codes, etc.	NFPA 52, NFPA 59	NFPA 52, NFPA 70, ANSI, ASME	Retail metering (CA DMS), NFPA 52, proposed NFPA 30

UBC= Unified Building Code; NFPA 52= National Fire Protection Association Code 52: Compressed Natural Gas (CNG) Vehicular Fuel Systems Code, 1998 Edition; NFPA 70= National Fire Protection Association Code 70: National Electrical Code; CCR= California Code of Regulations; ASME= American Society of Mechanical Engineers; NEC= National Electrical Code; ANSI= American National Standards Institute

Time Horizon for Full Technological Maturity

In addition to natural gas supply and price issues, expansion of the CNG infrastructure will depend on growth in deployment of high-fuel-use vehicle sectors. In the heavy-duty sector, where the largest volumes of fuel are consumed, CNG is facing a major challenge from LNG as the preferred form of natural gas fuel. For light- and medium-duty NGV applications, which have long been dominated by the conventional CNG fueling option, L/CNG is emerging as a very attractive alternative for certain fleets. In addition, regulatory drivers are currently minimal for using AFVs in the LDV and MDV sectors: conventionally fueled vehicles already meet stringent emissions standards, and energy-related regulations such as EPACT do not include requirements that have been effective in stimulating alternative fuel use.

In early 2000, the four major “turnkey” providers of CNG were surveyed about the current and future state of the CNG business in California. Among the findings of the survey were the following:

- Two of the three current providers of CNG indicated that their growth projections for the expansion of CNG stations are high. The third current provider projected medium growth. The fourth company has decided to focus its business on providing LNG and L/CNG instead of conventional CNG.
- Only one of the four companies indicated that government funding is of high importance in the future of natural gas fueling stations. The far greater driving factor for all of these companies is a high return on investment through major, immediate fuel demand and throughput. However, government funding for end users was identified as essential in the early years of commercialization.

To follow up on this information and expand the database, these same companies were sent infrastructure surveys in mid 2000. Several of California’s natural gas utilities were also sent this survey. Table 27 summarizes part of the input that was received from these TAG members.

Table 27. Summarized survey responses on long-term horizon for CNG

Survey Parameter	SoCal Gas, SDG&E and Long Beach Gas	Pacific Gas & Electric	Trillium USA	FleetStar, Inc.	Pickens Fuel Corporation	Pinnacle CNG Company
Expected Timeframe for Full Commercialization	~10 years	Now	10 years	5 years	Now	Now
Number of Fueling Stations Needed in California	100 public access stations in the South Coast region	Now	Depends on definitions	Unknown – gasoline equivalent should be the target	Each station is a stand-alone profit center. Critical mass not needed.	Now
Throughput Needed for Full Commercial Status (GGE/Month)	18,000 to 21,000	Now	20,000	10,000	20,000 for "breakeven" point for PFC and customer	Now

These same companies and other TAG members provided input on their existing RD&D activities for the CNG infrastructure, and their priorities for additional efforts. Table 28 summarizes this information. TAG members were also asked to identify the most important barriers to a sustainable CNG infrastructure, and the types of existing and new incentives that can help overcome those barriers. That input is summarized in Table 29.

Table 28. Summarized responses on RD&D for CNG infrastructure

TAG Member	Existing Infrastructure RD&D	Priority List for Further RD&D
The Gas Company	New public dispenser (3600 psig, 10 GGE/min) New debit card Improved billing card system and dispensers for all public stations	Universal control terminal and billing system/system changeout Standardized fueling pressure-temperature/dispensing controls Greater standardization of equipment Measurement between fuel control terminal and utility fueling meter
California NGV Coalition	Ongoing work with GTI IWG RD&D is focused toward greater efficiency through standard-ization and modularity	Standard state-wide design that incorporates all fire/safety and code conformity Fuel network development and demonstration
PG&E	Ongoing work with GTI IWG	Dispensing algorithm, low-cost compressor
Trillium USA	Ongoing R&D and commercial deployments	Access to continuous (web-based) updates of current infrastructure and related projects
FleetStar, Inc.	Ongoing R&D with GTI IWG	Cost reductions for stations and equipment
Pickens Fuel	Looking at different technologies to dispense fuel, welcome R&D beta sites for fuel delivery and production	Reliable card readers
Pinnacle CNG	Higher compression efficiency	(None provided)
South Coast AQMD	Investigating feasibility of modifying existing stations for greater use by HDVs	(None provided for CNG)

Table 29. Summarized responses on existing barriers and needed incentives

TAG Member	Major Barriers to Infrastructure Expansion	Incentives Needed to Overcome
The Gas Company	Throughput requirements Equipment and station costs Lack of common card system, and gasoline ease-of-use	Tax breaks at Federal and State levels Tax relief for cost of natural gas More grant funding for capital costs Rebates from OEMs and regulating entities Special funding to convert all card systems and dispensers in the State
California NGV Coalition	Permitting delays, variable utility service extension policies, delays in vehicle incentives, fuel card authorization Bare bones “commercial only” perception	(Funding for) fueling network demonstration Pro-CNG PUC policy on service extensions Local agency education and incentive expediting
PG&E	Cost and location with available gas	Tax incentives and grant funding
Trillium USA	Increased fuel demand	Fleet incentives and mandates to use fuel (not just buy vehicles) Reduced fuel sales tax (Expanded access to) HOV lanes
FleetStar, Inc.	High cost of stations	Funding and tax incentives
Pickens Fuel	Slow delivery of OEM vehicles	Greater demand for vehicles (and fuel)
Pinnacle CNG	Available vehicles and mandated changes	Tax incentives for station operator and end user / fleet
South Coast AQMD	Cost, cost, cost Fleet perceptions that fueling must be on-site	A continuing source of infrastructure funding is needed The current CNG network is tailored to LDVs while demand is for HDVs.

Detailed input about the expected timeframe for full commercialization of the CNG infrastructure was provided by the California Natural Gas Vehicle Coalition (CNGVC).
Table 30 provides a summary of specific input about station expansion requirements received from CNGVC executives. CNGVC executives believe that continued growth can be sustained for the next 15-20 years, after which it may be possible and necessary to convert the CNG infrastructure over for compression of hydrogen (for fuel cell vehicles) that is reformed from natural gas on site. The CNGVC acknowledges that continued growth will require lower-cost stations achieved through a variety of advancements (e.g., increased efficiency through standardization and modularization of stations).

Table 30. Projected need for expansion of CNG stations in California.

Market Element	Current	Projected Future Need
Number of CNG & L-CNG Stations	230	2,500
Share of Vehicle Fuel Market (by Volume of Fuel Dispensed)	0.3%	6%
Approximate Gasoline Gallon Equivalents (GGE) Pumped / Year	50 Million	1 Billion
Approximate GGE / Station / Year	217,391	400,000
Approximate GGE / Station / Month	18,116	33,333

Source: survey input from the California NGV Coalition, mid 2000

Advanced Infrastructure RD&D for CNG

Several major programs are underway to improve the commercial viability of CNG fueling stations. These programs involve a wide variety of public and private entities, but all are basically designed to 1) reduce lifecycle costs, and 2) improve performance, efficiency, and customer access / ease of use. Table 31 summarizes some of these major efforts.

In addition, there are a number of new activities underway to fund new, state-of-the-art CNG fueling facilities. For example, the SCAQMD recently approved "creative settlements" with the Los Angeles Department of Water and Power and AES Alamitos, LLC, for violations of rules and permit conditions. Included in the settlements is a requirement that each entity provide $6.0 million towards expansion of public-access natural gas fueling stations in Southern California. The SCAQMD Board designated $6 million from an AES settlement of to fund clean fuel infrastructure projects for natural gas vehicles. In March 2001, SCAQMD issued an RFP allocating $4.6 million to build multiple natural gas fueling station for public access and up to $1.4 million to construct or upgrade publicly accessible natural gas fueling stations for use by taxicabs and other natural gas vehicles.[79]

[79] South Coast Air Quality Management District, Board Agenda No. 3, February 16, 2001.

Table 31. Major RD&D efforts to improve the CNG infrastructure

Name of CNG Infrastructure Program	Participants	Major Program Objective(s) and /or Projects	Time-frame
Next-Generation Natural Gas Vehicle	Govt.-industry consortium headed by DOE-NREL, with 33 other agencies / companies / organizations	♦ Support next-generation NGVs by enhancing CNG fueling and maintenance infrastructures	Ongoing through at least 2004
Gas Technology Institute Infrastructure Working Group, (CNG Subcommittee)	Govt.-industry consortium headed by DOE and GTI, with ~ 25 other agencies / companies / organizations	♦ Recommended practices for station design, construction and operation ♦ Station bid specification handbook ♦ Technology exchange forum ♦ Electronic access and billing network ♦ Consistent fuel metering technology ♦ Improve metering systems ♦ Enhanced fueling nozzles	Ongoing through at least 2002

Summary of Major Barriers and Impediments

Removing barriers to the CNG fueling network is a high priority for proponents of natural gas vehicles. Vehicle expansion will depend on a significant increase in the number of fueling stations, in parallel with a major increase in vehicle demand. Both private fleet and public access stations are needed, but neither type is likely to be successful unless the private sector can achieve a sufficient return on investment by selling high volumes of fuel. Specific threats and barriers to expansion of the network for conventional CNG stations include the following:

- Competition from conventionally fueled vehicles for low emissions, especially in LDVs and MDVs
- Lack of effective fuel-use requirements in existing energy-related regulatory drivers
- California's ongoing energy crisis in general, and competing demand for natural gas to fuel new power plants, in particular
- High capital, operation and maintenance costs for CNG stations
- Lack of standardized, modular station design
- Lack of an open architecture for CNG station card readers
- Constraints in the natural gas pipeline system, or lack of sufficient gas supply for transportation use in some California regions
- Competition from LNG to capture greater market share in heavy-duty applications (see Section 4.2.2)
- Competition from L/CNG stations to reduce demand for conventional CNG stations (see Section 4.2.3)

4.2.2 LNG Fuel and Stations

Natural gas liquefies at very low temperatures (minus 258 degrees Fahrenheit at ambient pressure). Advantages of LNG include the fact that it is relatively free of impurities (98% methane) and has an energy storage density about 3.5 times that of CNG. While the energy density of LNG is nearly as high as conventional fuels (gasoline and diesel), it must be stored at very low temperatures, while controlling its high volatility to minimize boiloff (evaporation). This requires properly designed cryogenic equipment consisting of double-walled, stainless steel "superinsulated" vacuum tanks that limit energy transfer (heat) from outside the tank to the cold liquid inside. Because on-board storage of LNG is most conducive to larger vehicles, LNG is used primarily in HDV applications such as transit buses, refuse trucks, long-haul trucks and locomotives. As it is drawn from the onboard fuel tanks, LNG is vaporized from the engine's heat. Thus, the fuel that enters the engine is a gaseous mixture as in CNG vehicles, but of higher purity methane.

Number of Stations

As of early 2001, there are an estimated 135 LNG-fueled vehicles in California. These vehicles consume about 2.5 to 3.0 million gallons of LNG each year, and are currently fueled at eight existing LNG stations (see Table 32). With annual demand expected to grow to approximately 13 million LNG gallons within another year[80] (see Figure 4-9), numerous additional LNG stations are currently under construction in California (see

[80] Source: from Zeus Development and Gladstein & Associates, Market Assessment of LNG as a Transportation Fuel in California, July 2000, for Arthur D. Little.

Table 33) or planned by 2004 (see Table 34). Many of these stations are being financed in part through government funds (e.g., the Energy Commission and air pollution control districts). Several existing or future stations include the L/CNG feature – this is discussed in the next section.

Table 32. Existing LNG and L/CNG stations in California, by owner / operator

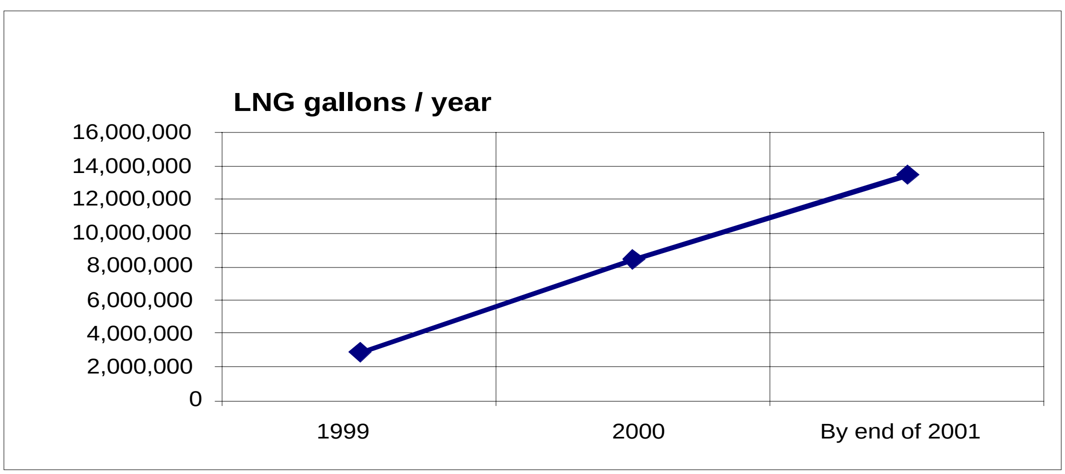
Station Operator / Name	Location	Capacity (LNG gal)	Major Vehicle Type Served
Harris Ranch	Coalinga	15,000	Diesel pilot Class 8 LNG trucks
L.A. Int'l Airport	Los Angeles	20,000	Dedicated LNG buses, dump trucks
Raley's	Sacramento	13,000	Dedicated LNG Class 8 trucks
Taormina Industries	Anaheim	Not available	Diesel pilot Class 8 refuse packers
FleetStar / UPS*	Ontario	6,000	Dedicated LNG Class 8 trucks, misc.
Vons Groceries	Santa Fe Springs	15,000	Dedicated LNG Class 8 trucks
OCTA Garden Grove	Garden Grove	50,000	Dedicated LNG Transit Buses
Waste Management / Sunline Transit	Palm Desert	15,000	Dedicated LNG refuse packers and 2 "superbuses"
***L/CNG stations**			

Table 33. LNG and L/CNG stations under construction in California

Station Operator / Name	Location	Expected Opening	Major Vehicle Type Served
City of Sacramento*	Sacramento	2001	TBD
City of San Diego	San Diego	Early 2001	Diesel pilot / dedicated refuse packers
County of Sacramento*	North Highlands	2001	County Waste Management
Waste Management	El Cajon	2001	Dedicated refuse packers
City of Tulare*	Tulare	2001	Miscellaneous LD, MD & HDVs
***L/CNG stations**			

Table 34. Planned LNG and L/CNG Stations

Station Operator / Name	Location	Expected Opening	Expected Major Vehicle Type to be Served
City of Barstow*	Barstow	TBD	Transit buses
L.A. Dept. of Public Works	Sun Valley / East Valley	2003	Refuse haulers
OCTA Anaheim	Anaheim	2001-2002	Transit buses
OCTA Santa Ana	Santa Ana	2004	Transit buses
Riverside County	Riverside	2001	Burrtec waste haulers
Santa Monica Bus	Santa Monica	TBD	Transit buses
Omnitrans	San Bernardino	TBD	Transit buses
Omnitrans	Montclaire	TBD	Transit buses
Waste Management	Corona	TBD	Refuse haulers
City of Bakersfield	Bakersfield	TBD	TBD
Waste Management	Simi Valley	TBD	Refuse haulers
Waste Management	Palmdale	TBD	Refuse haulers
USA Waste (Waste Management)	Fresno	2001-2002	Refuse hauler & misc.
***L/CNG stations**			



Source: Zeus Development Corporation

Figure 4-9. Existing and Projected Near-Term LNG Consumption in California

Existing and Needed Fuel Throughput

As with CNG stations, LNG throughput at a given station is a function of the types and numbers of vehicles fueled, and the frequency of fueling events. Currently, LNG is almost exclusively used in HDV applications that are conducive to high fuel use (e.g., transit, refuse haulers, and Class 8 trucks). As a result, the existing LNG stations in California all tend to have high throughputs. According to input from TAG members, a typical range is 15,000 to 50,000 GGE per month.[81] The projected change in consumption of LNG in California shown in Figure 4-9 assumes that each vehicle will consume 20,000 gallons of LNG per year. At that rate of consumption, 15,000 to 50,000 GGE per month at a given station requires between 15 and 50 LNG trucks fueling about 25 days per month.

Current Price of LNG

LNG is taxed less than diesel fuel but more than CNG, although government fleets get special exemptions. At the time the TAG was surveyed in mid 2000, the average price per LNG gallon in California was approximately $0.50 without tax, or about $0.65 per gallon fully taxed.[82] Fleets such as Orange County Transit Authority have negotiated long-term contracts for LNG as low as $0.38 per gallon before tax.[83] The price of LNG has generally been less volatile than that of CNG during the recent energy crisis, suggesting that there is less direct correlation between the pipeline cost of natural gas in the Western U.S. and the resale of LNG by suppliers.[84] Still, prices have recently increased, and a long-term price for a large fleet today might cost about $0.55 per gallon or higher.

The economics of using LNG as a heavy-duty fuel largely depend on the relative prices of diesel and LNG. Table 35 compares a few plausible pricing scenarios for LNG and diesel, to estimate relative fuel prices to a large private HDV fleet on an energy equivalent basis.[85] This comparison takes into account the higher brake-specific fuel consumption (about 20%) currently exhibited by most dedicated spark-ignited heavy-duty natural gas engines. As just one scenario, it shows that LNG can be competitive with diesel (under the assumptions shown) when their untaxed prices are in the ranges of $0.60 and $1.00 per gallon, respectively. However, this comparison does not consider all life-cycle factors (e.g., the cost of maintenance garages, vehicle incremental costs, etc.). A more detailed study is currently underway that compares the full-annualized life-cycle costs of LNG versus diesel in various types of a 50-unit HDV fleets. Preliminary estimates indicate that LNG can achieve overall

[81] Because LNG displaces diesel and not gasoline fuel, from the perspective of fuel consumption it is most useful to discuss LNG in diesel gallon equivalents (DGEs) instead of GGE. However, GGEs are the commonly used unit for fueling station throughput.

[82] From survey input by Erik Neandross of Gladstein & Associates, October 2000.

[83] Jim Ortner, Orange County Transit Authority, personal communication to Jon Leonard, 4/3/01.

[84] E-mail from Gary Pope, USA PRO, to Jon Leonard of Arthur D. Little, December 12, 2000.

[85] Fleets normally buy fuel before taxes, and then pay all applicable taxes to various agencies – this table assumes a private fleet paying all potential taxes. The federal excise tax for LNG is assessed on a per-gallon basis, while the State fuel use tax for LNG vehicles is a flat annual fee. The table shows an estimated conversion of that flat fee to a per-gallon basis.

cost parity with diesel when its before-tax price is roughly $0.64 per (LNG) gallon less than the untaxed cost of a diesel gallon.[86]

Table 35. Comparison of diesel and LNG price scenarios

	Diesel Price ($/gallon)		
	low	high	mean
wholesale rack price	$ 0.800	$ 1.200	$ 1.000
federal excise tax	$ 0.243	$ 0.243	$ 0.243
State fuel use tax	$ 0.180	$ 0.180	$ 0.180
Subtotal	$ 1.223	$ 1.623	$ 1.423
8.25% sales tax	$ 0.101	$ 0.134	$ 0.117
Total Price	**$ 1.324**	**$ 1.757**	**$ 1.540**

	LNG Price ($/gallon)		
	low	high	mean
wholesale price	$ 0.500	$ 0.700	$ 0.600
federal excise tax	$ 0.119	$ 0.119	$ 0.119
State fuel use tax	$ 0.008	$ 0.008	$ 0.008
Subtotal	$ 0.627	$ 0.827	$ 0.727
8.25% sales tax	$ 0.052	$ 0.068	$ 0.060
Total Price per LNG Gallon	$ 0.679	$ 0.895	$ 0.787
Total Price per DEG	$ 1.152	$ 1.520	$ 1.336
Total with 20% BSFC Penalty	**$ 1.383**	**$ 1.824**	**$ 1.603**

	Range of Diesel versus LNG Cost Differentials [$/DEG]					
	Diesel	LNG	Difference	Relative Cost		
Best-case LNG pricing	$ 1.757	$ 1.383	$ (0.374)	LNG cost is	-21%	**lower** than diesel
Worst-case LNG pricing	$ 1.324	$ 1.824	$ 0.500	LNG cost is	38%	**higher** than diesel
Average LNG pricing	$ 1.540	$ 1.603	$ 0.063	LNG cost is	4%	**higher** than diesel

Definitions: BSFC = Brake Specific Fuel Consumption, DEG = Diesel Equivalent Gallon

Station Capital Costs

According to input from TAG members involved with LNG infrastructure development, the capital cost of building an LNG station (~15,000 gallon capacity) ranges from $650,000 to $800,000 (excluding land costs). These estimates are consistent with information provided by Chart Applied Technologies, a major vendor of LNG fueling stations. As of early 2001, Chart's prices (including setup, installation and operational training) range from about $50,000 for a single-hose "demonstration fueler," to about $1.37 million for a top-of-the-line LNG station with four dispensers (see Table 36). However, other sources indicate that high-throughput LNG stations for large fleets (50,000 gallons of storage) can cost as much as $3.0 million for fueling station hardware, and $4.5 million when taking into account all necessary site and building upgrades.[87]

[86] Arthur D. Little, Comparison of Annualized Life-Cycle Costs: SI-LNG Versus Diesel in a 50-Unit Fleet with 8-Year Replacement Life, preliminary model, April 2001.

[87] Jim Ortner, Orange County Transit Authority, personal communication to Jon Leonard, April 3, 2001.

Table 36. Ranges of LNG Station Prices from Chart Applied Technologies

Station Type (Designation)	# of Dispensers	Storage (LNG gal)	Fleet Size (# of HDVs)	Station Price Range (with Installation)
Demonstration Fueler (VLNG 230)	1	Not Available	1-2	~$50,000
Mobile Refueler without truck purchase (ORCA)	1	Not Available	10-30	~$150,000 to $230,000
Lowest Cost Integrated Skid, no fuel metering (Skidded 6000)	1	6,000	27-60	~$250,000 to $500,000
Base Fueling Integrated Skid, 10% accuracy meter (Std. 15/1)	1	15,000	27-60	~$500,000 to $610,000
Modular Station, Weights and Measures Dispenser (Mod.15+/1)	1	15,000+	27-60	~$600,000 to $650,000
Modular Station, W&M Dispensers, capability for adding more storage (Mod.15+/2)	2	15,000+	27-80	~$600,000 to $700,000
Modular Station, W&M Dispensers, capability for adding more storage (30+/3)	3	30,000+ (2X15,000)	75-135	~$1,100,000 to $1,200,000
Modular Station, W&M Dispensers, capability for adding more storage (30+/4)	4	30,000+ (2X15,000)	75-175	~$1,200,000 to $1,250,000
Standard Station, W&M Dispensers (45/4)	4	45,000 (3X15,000)	135-210	~$1,250,000 to $1,375,000
Source: adapted from materials provided by Chart Applied Technologies, LNG Vehicle systems Training Seminar, February 2001.				

Station Operation, Maintenance and Training

On a fuel throughput basis, LNG stations have significantly lower O&M costs than CNG stations. The main reason is that LNG stations do not need gas compression and drying systems. Still, LNG stations require significant scheduled maintenance activities. Similar to the situation with CNG, “turnkey” LNG providers are emerging that are willing to manage all aspects of a LNG facility’s installation, operation, and maintenance, in exchange for an agreement by the customer to purchase a minimum throughput of fuel for a set period of time. Pickens Fuel Corporation is one such operation that offers “take or pay” agreements to fleets with very large throughputs of LNG. According to Pickens Fuel Corporation, the fully burdened maintenance costs for a large LNG station (30,000 LNG gallons per month, or about 17,700 diesel-gallon equivalents) is $0.03 to $0.06 per LNG gallon. This amounts to an annual maintenance cost of about $16,200 for an LNG station of this size.[88] Other LNG experts have indicated that “typical contracts for LNG station maintenance are $10,000 to $12,000 per year plus parts.”[89]

[88] Survey received from Jim Harger, Vice President of Marketing, Pickens Fuel Corporation, December 6, 2000.

[89] E-mail from Gary Pope, USA PRO, to Jon Leonard of Arthur D. Little, December 12, 2000.

Training for end users (vehicle refueling and safety) is typically provided with the cost of the station, but it may be limited to one or two days with no provision for follow-up training. Large anchor fleets such as the Orange County Transit District provide their own training and safety programs for the use and maintenance of its LNG stations.

Public Access: Hours and Accommodations

Most LNG stations are used primarily by large heavy-duty anchor fleets. Consequently, providing full public access is not necessarily a priority. However, many stations are designed for 24-hour access with a cardlock system, with point-of-sale options that are similar to comparable CNG stations. Table 44 provides a summary of the input received from TAG members about current point-of-sale options, activities, and needs in this important area.

Table 37. Point-of-Sale Payment Options, Activities and Needs for LNG Stations

Source	Current Point-of Sale Options	Point-of-Sale Activities and Needs
Pickens Fuel Corporation	EJ Ward in California Autogas in Arizona	♦ Investigating user-friendly payment, i.e., MasterCard and Visa accessibility ♦ Lack of reliable card readers is the "weakest link" in stations
ALT-USA	CFN	♦ Need assurance of user training ♦ Need release of liability
Gladstein & Associates	Varies by site. Most stations have unique card reading systems, some have no system and transactions must be manually recorded	♦ Ability for fueling stations to accept Visa or MasterCard

Source: surveys received from TAG members

Building Codes and Standards

LNG stations must meet similar standards and codes as CNG stations, although the main requirements are NFPA 57 (Liquefied Natural Gas Vehicular Fuel Systems Code, 1999 Edition) and NFPA 59A (Standard for the Production, Storage, and Handling of Liquefied Natural Gas, 1996 Edition).

Time Horizon for Full Technological Maturity

Arthur D. Little, in conjunction with Zeus Development Corporation and Gladstein & Associates, is in the process of performing an assessment of the potential for LNG to become a major transportation fuel in California.[90] Included in the work to date is a preliminary market assessment by Zeus Development[91] that reviews all financial aspects of the LNG business, i.e., liquefaction plants, on-board LNG fuel tanks, fueling stations, and vehicle

[90] This work is being funded by Brookhaven National Laboratory and the Gas Technology Institute.

[91] Zeus Development Corporation, Market Assessment of LNG as a Transportation Fuel in California, July 2000, for Arthur D. Little

conversions. Costs amortized over a twenty-year period were estimated for various types of HDV fleets using LNG.

As might be expected, this study found that the economic viability of LNG in California for heavy-duty vehicles will be closely tied to several key factors, including the relative prices of LNG and diesel, the number of LNG vehicles deployed, and the existence of tax deductions and incentives for end users. Initially at least, competitive economics will most likely be achievable only in large fleets of transit buses, waste haulers and Class 8 trucks. Arthur D. Little and its team members are now using such information to develop proposed objectives for the LNG industry to achieve by 2010. These aggressive objectives are thought to be achievable, with sufficient levels of investment. Table 38 provides a summary of the key parameters under the proposed objectives regarding number of vehicles and fueling stations, fuel throughput, and estimated associated costs.

The number of vehicles cited in Table 38 – 6,000 LNG-fueled trucks, buses and refuse haulers – is consistent with the expected demand for heavy-duty AFVs that is being created through key regulatory drivers, such as SCAQMD's Rules 1192 (transit buses) and Rule 1193 (refuse haulers). Still, it is recognized that many significant barriers must be overcome for LNG to become a major transportation fuel in California. Table 39 summarizes the input received from TAG members regarding these key barriers, and their expected timeframe for full commercialization. Note that one LNG station provider that serves large LNG fleets considers the technology to be already fully commercialized, because "each station is a stand-alone profit center." This is a clear indication that high-volume sales of LNG are the key to its commercialization.

Table 38. Proposed objectives for LNG industry by 2010

Parameter of LNG Business	Proposed Industry Objectives
Number of LNG trucks, buses and refuse haulers	~6,000[92]
LNG fuel sales (gallons per year)	~120 million
Number of LNG stations	44
Number of New LNG Plants and Associated Bulk Storage Tanks	33
Total needed capital investments (Year 2000 $): Low Estimate: High Estimate:	 $167 million $334 million
Minimum cost sharing target from government grants and incentive programs, @ 20%[a] Low Estimate: High Estimate:	 $33 million $67 million
Annual target for gov't cost share (next 9 years) Low Estimate: High Estimate:	 $4 million $7 million

Source (except [a]): Preliminary projections made by Arthur D. Little and its subcontractors as part of "Concept Tactical Plan," project entitled: LNG as a Heavy-Duty Vehicle Fuel, for the Gas Technology Institute and Brookhaven National Laboratory. [a] Based on 4:1 cost share ratio targeted by Energy Commission and SCAQMD programs. Actual cost sharing requirements may vary by agency, type of incentive or grant, enabling legislation, etc.

Table 39. Summarized survey responses on long-term horizon for LNG

Issue / Parameter	Gladstein & Associates	ALT USA	Pickens Fuel Corporation
Expected Timeframe for Full Commercialization	10 Years	5 Years	0 to 1 Years
Number of Fueling Stations Needed in California for Full Commercialization	20 to 30	Equivalent numbers to current diesel stations	Each station is stand-alone profit center. Critical mass not needed, profitability guaranteed in pricing / volume requirements of each station's contract
Throughput Needed for Full Commercial Status	15,000 to 25,000 LNG Gal/ Month	10,000 LNG Gal/ Month	About 20,000 LNG Gal/Month
Major Barriers	• High capital costs • Lack of acceptance by trucking industry	• High capital costs	• Long lead time for OEM vehicles
Priority R&D Needs	• Low-cost equipment • Reliable nozzles • Improved saturation techniques • Common nozzle fittings • Reduced or zero-loss (boil-off) fuel storage	• Low cost stations	• Reliable card readers

Table 40 provides examples of RD&D efforts that are underway to help overcome these barriers.

[92] Based on capturing 10% of the estimated 60,000+ HDV market in California conducive to LNG operation.

Table 40. Major RD&D efforts to improve the L/CNG infrastructure

Name of L/CNG Infrastructure Program	Participants	Major Program Objective(s) and /or Projects	Time-frame
Next-Generation Natural Gas Vehicle	Gov't.-industry consortium headed by DOE-NREL, with 33 other agencies / companies / organizations	• Support next-generation NGVs by enhancing L/CNG fueling and maintenance infrastructures	Ongoing through at least 2004
Gas Technology Institute Infrastructure Working Group, (L/CNG Subcommittee)	Gov't.-industry consortium headed by DOE and GTI, with ~ 25 other agencies / companies / organizations	• Development and deployment of small-scale liquefaction plants • Development of low-cost LNG fueling stations • Development of cost-effective LNG pumps • Standardized LNG nozzles and receptacles • Breakaway devices for LNG dispensing hoses • Economical odorant for LNG • Recommended practices for LNG • Assessment of impact from low-lubricity CNG at L/CNG stations, and possible solutions	Ongoing through at least 2002

LNG-Specific Supply and Demand Issues

Supply and demand for natural gas as a commodity was discussed above, with an emphasis on ramifications of the current energy crisis. LNG is currently imported to the U.S. on both the East and Gulf coasts. Virtually all LNG product consumed in California is currently transported into the state by truck, rail or ship. It is estimated that the near-term potential supply of LNG in the Western United States is approximately 133 million LNG gallons per year. The existing demand for LNG in California is about 3 million gallons per year, and the annual demand by the end of 2001 is expected to be about 13 million gallons (a 400% increase). Thus, according to at least one source, it appears that there will be a sufficient supply of LNG to meet the immediate California market demand.[93] However, recent concerns have been expressed that the supply of LNG in California over the next several years will be insufficient to meet fuel demand from the anticipated growth of LNG vehicles, due to the ongoing energy crisis and other emerging market factors.

[93] Zeus Development Corporation, Market Assessment of LNG as a Transportation Fuel in California, July 2000, for Arthur D. Little

Significant new developments have recently been announced regarding plans to bring more LNG to California. In early 2001, Phillips Petroleum Co. and El Paso Corp. signed a letter of intent for El Paso's long-term purchase of LNG from a plant to be built by Phillips near Darwin, Australia. According to a joint press release, Phillips and El Paso will develop an LNG receiving terminal (probably in Mexico) and beginning in 2005 680 million cubic feet per day of natural gas (about 8.7 million LNG gallons) will be offloaded for delivery to markets in California and Mexico. However, this LNG will be used for "peak shaving" purposes and distributed to customers as gaseous methane through existing pipelines.[94]

Chevron is also investigating a plan to bring LNG to California and re-gasify it for distribution through the pipeline system, in direct response to the energy crisis. If feasible, Chevron will ship LNG to California from its "extensive gas holdings in Australia," with new supplies arriving in the 2005 timeframe. Chevron did not specify how much LNG it may import, but stated that the primary end-use target would be to fuel "new and existing electric power generation plants."[95]

If these new LNG sources come to fruition, more pipeline natural gas will be available to fuel new electricity plants. This will help alleviate the overall natural gas supply crunch, possibly freeing up additional feedstock to produce LNG for transportation fuel. Still, concerns are growing that competing demands for natural gas will result in insufficient fuel volumes for California's growing LNG vehicle population. As this report was being finalized, Applied LNG Technologies announced the intention to add several new 5,000 gallon-per-day LNG liquefaction facilities in California and Texas, specifically to supply the California transportation market. The source of methane for liquefaction will be landfill gas and other renewable, indigenous supplies. Still, it is likely that California will need to be proactive in developing new sources for LNG and other alternative transportation fuels.

Advanced Infrastructure RD&D

One way to increase the natural gas supply for transportation in California is to accelerate deployment of "waste-to-energy" technologies. For example, decomposition of biomass, industrial waste, and municipal solid waste produces tremendous amounts of natural gas in California, as does anaerobic digestion of organic waste. All together, there are more than 100 existing waste-to-energy plants in California. Most of these are used to generate electricity, and currently supply about two percent of California's total electrical capacity. However, waste-to-energy technologies represent a large untapped resource in California for production of natural gas. These processes typically produce gas that is relatively low in methane content (between 55 and 75 percent), and therefore considered low to medium in energy content. However, depending on the extent of the cleanup processes used, the gas can be used to generate power or electricity in engines and even fuel cells.

Limited efforts are already underway to develop "small-scale liquefaction" plants that can use remote or renewable gas sources to produce LNG, at or near the end user's fueling station. Perhaps the biggest barrier to this approach is that gas cleanup costs from landfill

[94] "Philips and El Paso to Bring Australian LNG to California," Oil & Gas Journal (Online Story), March 8, 2001.

[95] Chevron Corporation, "Chevron Announces Gas Utilization Study," Press Release, March 19, 2001 from http://www.chevron.com/newsvs/.

sources can be significant. As a pilot project, such a gas-to-liquid effort is being attempted at San Diego County's South Chollas landfill, with cost sharing from the Energy Commission. Methane will be captured from the landfill, cleaned up and liquefied to LNG, and used to fuel the City of San Diego's LNG refuse haulers.

Meanwhile, efforts are underway in California to develop and demonstrate cost-effective small-scale liquefaction plants using pipeline gas. For example, PG&E will install a small-scale (10,000 gallon per day) liquefier on the riverfront in Sacramento. The fuel will be used at a new L/CNG station for the County of Sacramento, which will have two LNG dispensers and two CNG dispensers. The small-scale liquefier is expected to be in operation by mid 2001, with the L/CNG station coming on line several months later. According to PG&E, the station will cost less than $500,000 and will fit on a 10 ft. by 12-ft. platform.[96]

Especially in lieu of the energy crisis, additional efforts are needed to produce LNG and other clean transportation fuels from unconventional feedstock. Potential strategies include further exploiting California's large untapped resources of waste-to-energy technologies, and using emerging gas-to-liquids technology to extract stranded reserves of associated natural gas, which can yield LNG, zero-sulfur synthetic diesel fuel, and methanol (among other useful products).

Summary of Major Barriers and Impediments

There are a number of key barriers and impediments for the LNG infrastructure in California. Many of these are similar to CNG, except that LNG is fully focused on the HDV sector, unlike CNG. The most critical barriers for expanding the LNG infrastructure include:

- California's ongoing energy crisis in general, and competing demand for natural gas to fuel new power plants, in particular
- Relatively few engine and vehicle models compared to diesel
- Long lead times to obtain vehicles
- High cost of fueling stations and vehicle components (especially on-board LNG tanks)
- Lower engine efficiency compared to diesel (for most engines)
- Insufficient fuel consumption to attract private investment except at big stations with large HDV anchor fleets

4.2.3 L/CNG Stations

A third type of natural gas fueling facility, known as an "L/CNG" station, is a specialized LNG station that also supplies CNG. Such stations consist of a conventional LNG system, with the addition of high-pressure cryogenic pumps that compress some of the LNG to 4,000–4,500 psi, and then vaporize the highly compressed liquid. CNG derived from this process offers several advantages over conventional CNG. First, cryogenic pumps require significantly less energy than the compressors used at conventional CNG stations, and are

[96] Information provided by Brian Stokes of PGE during LNG Project Advisory Committee Meeting, ADLittle's Fullerton Office, 2/12/01.

less maintenance intensive. Second, L/CNG is delivered to the natural gas vehicle at ambient temperature, facilitating complete fills while obviating the need for temperature compensation systems.[97] In addition, since LNG itself is nearly pure methane (98%), L/CNG is delivered to the vehicle with virtually no contaminants or undesirable fuel elements such as oil carryover, moisture, and higher hydrocarbons. This eliminates the need for elaborate gas drying and filtering systems.[98]

Adding the L/CNG option when building a new LNG station costs approximately $150,000 to $200,000. Retrofitting an existing LNG station with the L/CNG feature costs approximately $200,000 to $250,000.[99] Despite these additional costs, L/CNG stations have potential to be cost-effective alternatives to conventional CNG stations. The capital costs of a large (transit-bus-sized) L/CNG station can be nearly 50% lower than a conventional CNG station of comparable size.[100] Operation and maintenance costs can also be significantly lower. However, L/CNG is currently offered at only a few California locations (refer back to the tables on page 60).

L/CNG provides an integrated NGV strategy for fleets by enabling refueling of light-duty CNG vehicles and heavy-duty LNG vehicles at the same facility. For example, at the Ontario L/CNG station, United Parcel Services refuels both LNG and CNG package-delivery vehicles, and also offers a public-access side for both fuels. However, it must be emphasized that L/CNG facilities are integrally linked to LNG fueling stations, because they require an on-site supply of liquefied natural gas. Only 44 LNG stations are expected to be operational in California by 2010 (refer back to Table 38 on page 67). By contrast, to sustain NGV commercialization, approximately 2000 new fueling facilities that dispense CNG will be needed in California by the same timeframe. Clearly, conventional CNG stations rather than L/CNG stations will meet the bulk of that demand.

In addition, more information is needed to assess the long-term performance, reliability, and life-cycle costs of L/CNG stations. One key question about L/CNG involves its lack of lubricity for some natural gas vehicle fuel injectors. Since compressed fuel from an L/CNG station has very low lubricity, at least one NGV manufacturer has indicated that injector warranties may be void when using L/CNG. This is the opposite problem encountered with conventional CNG, which can have too much “oil carryover” from the natural gas compressor, resulting in damage to the gas injection system and other parts of the NGV. The natural gas industry is working to resolve these issues as quickly as possible, but has not made this a top priority.

[97] Different CNG compression strategies have a significant effect on gas temperature, and therefore fill completeness. Pinnacle CNG has been an industry leader in improving CNG fills using advanced temperature compensation, and other technologies. According to Pinnacle, its Hydraulic Intensifier Compressor (HIC) can discharge 4,000 psi CNG at up to 100°F lower than a conventional 1,800 rpm four-stage reciprocating compressor.

[98] Transportation Research Board, *TCRP Report 38: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations.*

[99] This information is based on ADLittle’s experience preparing L/CNG station RFPs, and input provided by 1) Steve Bartlett of ALT USA and 2) Chart Applied Technologies.

[100] Natural Gas Fuels, *Fueling Stations from A to Z*, article by David Port, May 1999.

4.3 LPG Fuel and Fueling Stations

Propane, the main constituent of LPG, is a colorless, odorless, tasteless, and non-toxic hydrocarbon. Propane is a gas in its natural state, but it turns to liquid under moderate pressure. When used in vehicles, propane is stored in special fuel tanks and pressurized to about 200 psi. Similar to how LNG is used on vehicles, when liquid propane is drawn from the tank it is vaporized to a gas before being burned in the engine.

Most propane produced today is recovered from natural gas through a separation process called fractionation, but refining of crude oil is the predominant means of production in California due to the high concentration of refineries in the state. As a safety measure, ethyl mercaptan (an odorant that smells like sulfur) is added to propane when it is loaded into transport trucks or onto railcars. According to the nation's largest LPG supplier, propane is a generic commodity, so all retailers provide a very similar product. "Only service, safety, and dependability of supply differentiate suppliers."[101] Propane is shipped to retail storage sites through pipelines as well as on railcars, transport trucks, and barges. Bulk trucks typically make the final delivery in 1,800- to 5,000-gallon cylinder trucks.

Number of Stations

As of early 2001, there are approximately 1200 facilities in California that dispense propane. According to the Western Propane Gas Association, more than half of these facilities are capable of providing propane as a motor vehicle fuel. [102] However, today only about 2% of the total LPG dispensed is used for automotive applications (see Figure 4-10). The vast majority is used for petrochemical applications, and to fuel residential and commercial applications such as heaters, recreational vehicles and barbecues.

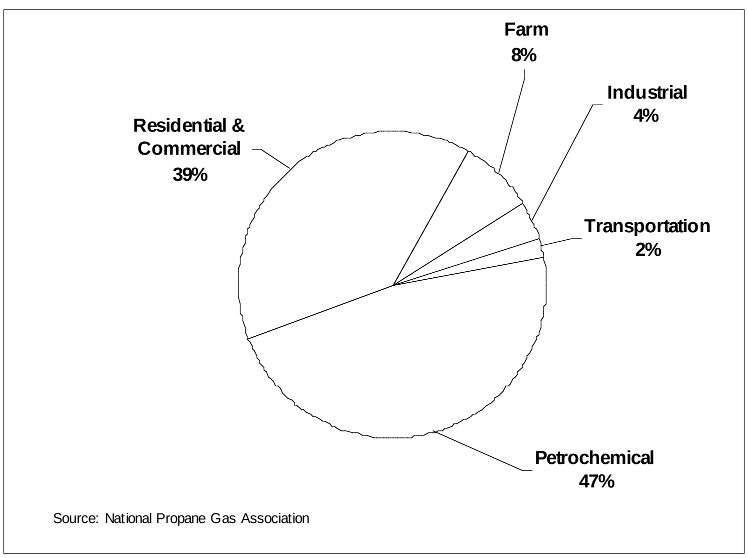


Figure 4-10. Current propane demand sectors

[101] From Ferrelgas website (www.ferrelgas.com).

[102] Information provided by Mr. Steve Moore of Mutual Liquid Gas.

Existing and Needed Fuel Throughput

California's existing LPG stations are well-dispersed in key locations, and are already self sustaining from non-vehicle fuel sales. LPG stations are generally owned and utilized differently than natural gas stations (CNG or LNG). First, LPG has long been used as a mainstream fuel for barbecues, outdoor heaters, forklifts and recreational vehicles. Second, LPG end users often own and operate their fueling stations, because they are inexpensive to install and have relatively low life-cycle costs.[103] As a result, the LPG infrastructure has had sufficient throughput to be self-sustaining without major use as a fuel for on-road AFVs, and government financial support has generally not been necessary. However, that would not necessarily be the case if LPG were to become a mainstream automotive fuel, with multiple dispensers located on typical gasoline fueling station islands.

LPG Demand, Supply and Price

Propane is produced as a by-product of natural gas processing and petroleum refining. Figure 4-11 shows the production and distribution chain for propane. Texas produces about one third of the nation's supply, and has more than half of the underground storage capacity. In addition to these two processes, demand is met by imports of propane and by using stored inventories. Although imports provide the smallest (about 10 percent) component of U.S. propane supply, they are vital when consumption exceeds available domestic supplies of propane. Propane is imported by land (via pipeline and rail car from Canada) and by sea (in tankers from such countries as Algeria, Saudi Arabia, Venezuela, Norway, and the United Kingdom).

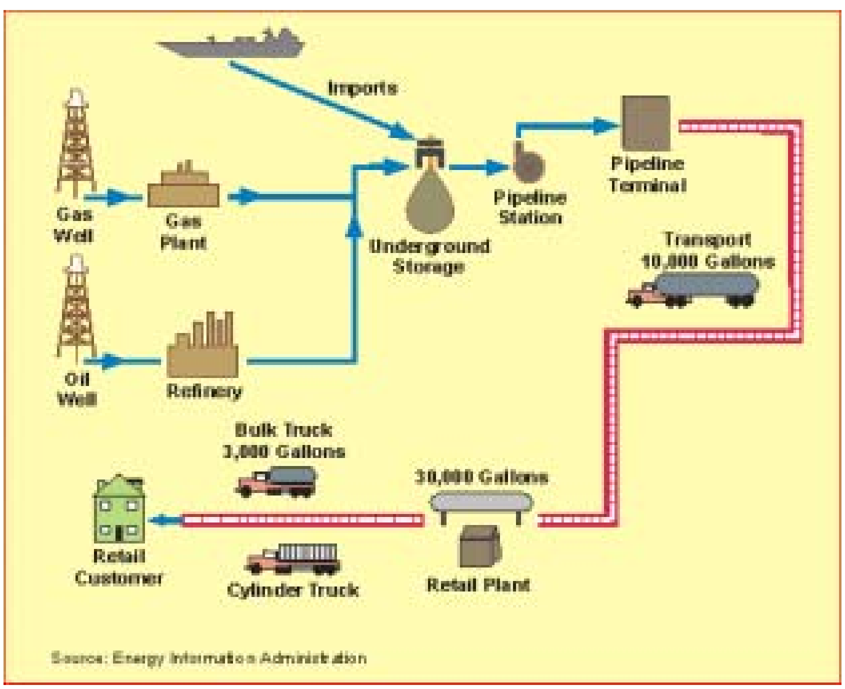


Figure 4-11. Production chain for propane (from http://www.npga.com)

[103] For example, LPG stations have no maintenance associated with gas compression and drying.

According to the LPG industry, domestic LPG supply is currently sufficient for 21 million vehicles per year.[104] Worldwide, there is ample LPG supply, but prices drive product distribution. Since U.S. suppliers compete in a global market for LPG, a sudden, heavy demand for LPG due to colder weather usually results in prices escalating rapidly.[105] The National Propane Gas Association recently acknowledged this concern with the following statement:

> "It is important to understand that the by-product nature of propane production means that the volume made available from natural gas processing and oil refining cannot be adjusted when prices and/or demand for propane fluctuate."[106]

Propane is traded on the commodities market; consequently, the price of LPG changes daily. LPG prices are subject to a number of influences; some are common to all petroleum products, and others are unique to LPG. Because LPG is essentially a portable fuel, it is typically used for home heating where natural gas pipelines don't exist. It can also serve many other different markets, from fueling barbecue grills to producing petrochemicals. The price of LPG in these markets is influenced by many factors, including the prices of its feedstocks (natural gas and crude oil); prices of competing fuels in each market; the distance LPG has to travel to reach a customer; and specific issues within individual markets served (e.g., residential, fork lifts, etc.).

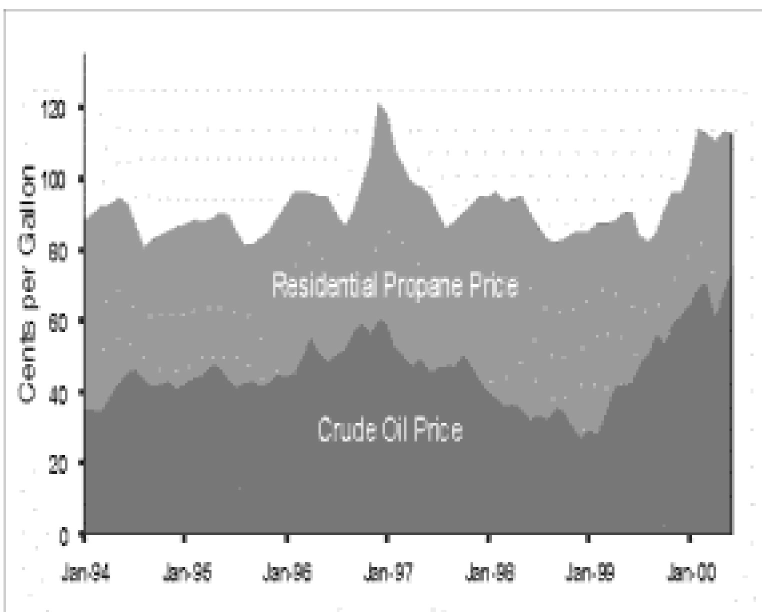


Figure 4-12. Retail LPG prices generally track those of crude oil.

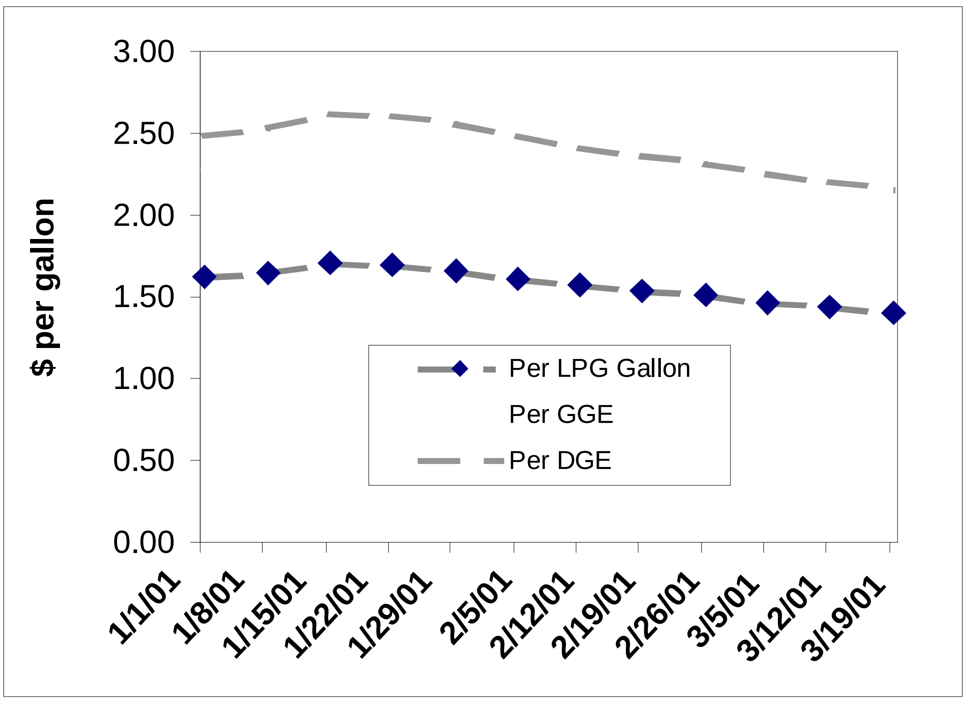
[104] Source: Website of the National Alternative Fuel Training Consortium (http://naftp.nrcce.wvu.edu/).

[105] The basic source of information from this section is from the websites of the National Propane Gas Association (www.npga.com) and the National Propane Council (www.propanecouncil.org). The source of most cost and price information is the Department of Energy's Energy Information Association (www.eia.doe.gov)

[106] National Propane Gas Association website (www.npga.com).

As Figure 4-12 shows, the retail price of propane closely tracks that of crude oil. Continuing high crude oil prices in late 2000 / early 2001 have impacted propane costs, as well as most energy prices. According to Purvin & Gertz, Inc., an international energy industry consulting firm, the following additional factors resulted in increasing LPG prices during the winter of 2000/2001.

- U.S. propane inventory levels are the lowest since 1996, even though stocks are continuing to build
- Record high natural gas prices
- Imports of propane to the U.S. are down over the last two years
- Demand increased in other regions and countries (especially China, Mexico, and the Middle East)



Source: Energy Information Administration

Figure 4-13. Recent trend in retail LPG prices, with GGE and DGE prices.

Figure 4-13 shows the average retail price of LPG in California over the first three months of 2001, with comparisons to gasoline gallon equivalents (GGE) and diesel gallon equivalents (DGE). It shows that LPG prices gradually came down since the beginning of the year. Recent checks indicate that the price is currently about $1.37 per LPG gallon ($1.92 per GGE, $2.11 per DGE) for self-service automotive applications. However, according to a propane distributor, the same dealer would likely sell LPG at a significantly higher price (currently about $2.00 per LPG gallon) when refilling portable 5-gallon tanks used for LPG barbecues. Like other types of fuel suppliers, the propane industry is willing to offer significant price breaks as a function of larger volumes pumped and reduced costs to assist customers.[107]

In 2000, the propane industry hired Purvin & Gertz, Inc. to further study propane market dynamics and industry infrastructure. Among the key conclusions from the study (released in October 2000) was that "overall propane supplies are adequate to meet the needs of the existing domestic retail propane market and to support additional growth in that market." However, the report went on to note that "the temporary supply outages and distribution delays encountered by many dealers over the past three years reflect a growing trend that could lead to far more serious outages and even higher price spikes" should severe winter weather conditions develop.[108]

At the time this study was released, U.S. propane inventories had risen to a high of 63 million barrels. The high level of inventory was attributed primarily to higher gas plant and refinery production of propane, and reduced consumption by the petrochemical industry. Despite these high amounts in primary storage, Purvin & Gertz noted concern that many propane marketers had not filled their secondary (dealer) or tertiary (end user) storage.

In early 2001, the propane industry asked consultant Purvin & Gertz to update its October 2000 propane infrastructure study, to assess the implications of continued low supply and high price levels. Purvin & Gertz concluded that "propane stock levels are currently depleting at all-time record rates." It was further noted that if cold weather conditions continue "we expect propane stocks in most regions to decline to modern day lows, likely testing minimum base supply levels." [109]

On February 2, 2001, the National Propane Gas Association released a press release[110] stating the following:

> "With propane inventories declining at all-time record rates and natural gas prices still two to three times their normal level, industry experts predict that propane prices will continue at their unprecedented high levels."

Station Capital Costs

Figure 4-14 compares the costs of building three types of public-access LPG stations. It shows that a stand-alone dispenser with point-of-sale networking costs about $30,000. If the LPG dispenser is built onto the gasoline island at a typical station, the cost is about $70,000. The same station with a 6,000-gallon, belowground LPG tank would cost about $100,000.

[107] Personal communication, Bill Platz, Delta Liquid Energy, to Jon Leonard, April 2, 2001.

[108] Propane Education & Research Council, Propane Market Dynamics and Industry Infrastructure, a summary of the Purvin & Gertz study, October 20, 2000, from the PERC website (http;//www.propanecouncil.org).

[109] The Near-Term Outlook for U.S. Propane Supplies, a follow-up study by consultant Pervin & Gertz on behalf of the National Propane Gas Association and other propane industry groups, February 5, 2001, obtained from NPGA website (http://www.npga.org/public/articles/Summary_of_PG_.pdf).

[110] National Propane Gas Association, press release, February 2, 2001, from website (http://www.npga.org/public/articles/details.html).

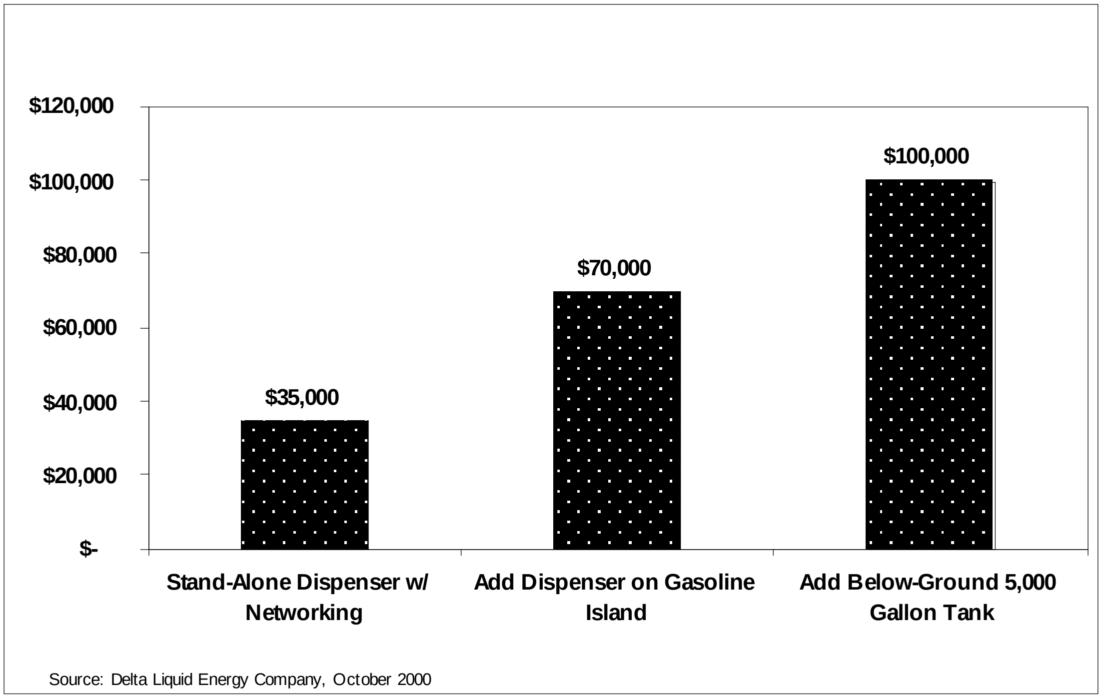


Figure 4-14. Estimated costs to build various types of LPG stations

Station Operation, Maintenance and Training

LPG stations are relatively simple systems compared to CNG or LNG stations. A typical station consists of an aboveground storage tank, a 2 to 4 horsepower transfer pump, and a meter and hose dispensing system. Unlike CNG stations, there is no need for a compressor or gas dryer. This makes an LPG station relatively easy to operate and maintain. The estimated cost per year to maintain a station is $1,000, according to Delta Liquid Energy Company.[111]

Fuel Quality

LPG comes in three different commercial grades, with varying compositions of propane other hydrocarbons, and miscellaneous other constituents. A minimum propane content of 90% by liquid volume is necessary for automotive applications, to ensure sufficient vapor pressure for delivery of the fuel to the engine, even at very low temperatures.[112] From an emissions standpoint, the propylene (also known as propene) content of LPG is of concern because it has a very high photochemical reactivity. Propylene does not occur in LPG obtained from natural gas processing plants, but it does in the LPG resulting from petroleum refinery operations. Primarily to control propylene content, the U.S. propane industry and regulatory agencies have developed an automotive propane standard known as HD-5. Fuel

[111] Survey input received from Bill platz, Delta Liquid Energy Company.

[112] Source: Website of the National Alternative Fuel Training Consortium (http://naftp.nrcce.wvu.edu/).

for spark-ignition engines in California must comply with this HD-5 specification, which is summarized in Table 41.

Table 41. HD-5 Specification for Automotive LPG

Parameter	HD-5 Propane Specification
Propane Content	90% liquid volume (min)
Propylene Content	5% liquid volume (max)
Butane and Heavier HCs Content	2.5% liquid
Moisture Content	Dryness test of NGPA
Residual Matter Content	0.05 ml
Total Sulfur Content	123 ppm by weight fraction

Public Access: Hours and Accommodations

Most public LPG stations to date have not been built for automotive fueling applications. Future stations designed for that purpose are expected to offer 24 hour access, seven days per week.

Building Codes and Standards

LPG stations must meet a variety of codes and standards, including but not limited to UPC, UFC, UBC, and NFPA 58. According to survey input from one TAG member, the need to comply with highly variable Fire Marshall requirements is a major challenge to building and installing LPG stations.

Time Horizon for Full Technological Maturity

As Table 42 shows, one LPG vendor hopes to install up to 30 new LPG stations in California for automotive applications. The timeframe envisioned is 12 to 18 months for this vendor to achieve these plans. One big challenge is the currently paucity of OEM offerings for dedicated LPG-fueled vehicles and engines, which may continue to hinder wider commercialization of LPG as a clean automotive fuel. Table 43 indicates that the average LPG station in California currently dispenses only about 1000 gallons of LPG per month, and most of this is for non-automotive applications such as barbecues and heating. A 15-fold increase in throughput per station is reportedly needed to achieve commercialization goals for automotive applications.

Table 42. Summarized survey response on horizon for automotive LPG stations

Issue	Response
Expected timeframe for full commercialization	♦ 12 to 18 months
Number of fueling stations needed in California	♦ 30 public access stations
Needed fuel volume per station	♦ 15,000 gallons (one hose)
Methods of financing additional stations	♦ Private capital and government programs (e.g., Carl Moyer).
Financial incentives and / or administrative actions needed to overcome barriers	♦ Need co-funding to offset capital costs (installation, permits, concrete, etc.)

Table 43. Projected need for expansion of LPG stations in California.

Market Element	Current	Projected Future Need
Number of Automotive LPG Stations	7 (for vendor)	At least 30 more
Approximate LPG gallons pumped per month, per station	1000 (very little for automotive use)	14,000 to 15,000
Approximate GGE pumped per month, per station	700 (very little for automotive use)	10,000 to 10,650

Source: survey input from Delta Liquid Energy

Summary of Major Barriers and Impediments

As previously noted, the LPG infrastructure has essentially already reached sustainable commercial status due to the fuel's use in non-vehicle applications. Automotive LPG stations are more complex and costly than LPG stations designed simply to fuel barbecue cylinders or forklifts, but they can be built at lower costs than natural gas stations. The biggest challenges to expanding the automotive LPG charging infrastructure in California are related to vehicle and fuel issues more than the fueling stations themselves. Specific impediments include the following:

- The threat of volatile, high prices due to distribution bottlenecks, storage imbalances, natural gas market dynamics, and other factors
- Low demand for LPG (as an automotive fuel), due to lack of commercially available dedicated LPG vehicles, and the absence of fuel-use requirements for bi-fuel vehicles
- High incremental cost of LPG-fueled vehicles and engines (especially for the heavy-duty sector)

4.4 Electric Vehicle Recharging Stations

As previously discussed in Section 3.1.3, electric vehicles (EVs) are expected to play an important role in California's long-term strategy to reduce mobile source emissions. Accordingly, EV charging stations are being installed throughout California. In Southern California, the Mobile Sources Reduction Review Committee (MSRC) has played a major role in funding charger installations for public access. Both public and private investors have begun to establish a skeletal network of EV recharging stations in the major regions of the state.

Number of Stations

Survey responses were received from two TAG members regarding the EV charging infrastructure. As shown in Table 44, these estimates indicate that there are nearly 3,300 EV chargers California. About 59% are inductive chargers and 41% are conductive. Virtually all provide Level II charging designed for 208 or 220 VAC power sources.

Table 44. Electric Vehicle Recharging Infrastructure in California

Charger / Station Type	Inductive	Conductive	Total
Public Access Charging Stations	617	378	995
Public and Private Fleet and Business Chargers	710	860	1570
Residential Chargers	600	126	726
Total Chargers	**1927**	**1364**	**3291**
Source: California Electric Transportation Coalition, in consultation with Clean Fuel Connection, Inc. and the Sacramento Municipal Utility District, Electric Transportation Infrastructure			

California's EV charging network has evolved to serve the state's largest concentrations of battery-electric vehicles. Consequently, stations are concentrated in three major areas of the state: the Los Angeles Basin, the North and South Bay Area, and Sacramento.[113] Within these regions, charging sites are generally located in places where people spend time, rather than along major thoroughfares (e.g., interstates).[114] This is because current-technology EVs require significantly longer time to "refuel" compared to conventionally fueled vehicles, or other types of alternative fuel vehicles. The basic strategy is to install chargers at key locations within metropolitan areas, allowing EV users to extend vehicle range through "opportunity" charging while shopping, attending sporting events, going to movies, etc.

In addition to the EV charging stations that are located throughout California at public agencies and private businesses, there are approximately 726 private residences in California wired for EV charging (see Table 44). The capability to "refuel" EVs at home is a significant advantage compared to using conventional vehicles.[115]

Existing and Needed Electricity Use Per Charger

More information is needed about the amount of electricity currently used at California's EV charging stations (per station and collectively). At this early stage of EV deployment, public stations do not receive enough use to consume large quantities of electricity. However, for fleets with large numbers of EVs, such as Southern California Edison's Toyota RAV EV fleet, electricity consumption per charger is very high, and substantial quantities of gasoline fuel are displaced through use of these EVs when comparing the same fleet using petroleum fuels on a per-capita basis.

[113] Survey input from the California Electric Vehicle Coalition, December 2000.

[114] Survey input indicated that discussions have occurred about a North-South corridor for EV charging in California, but no concrete plans have yet been made.

[115] NGVs can also be refueled (slow-filled) at home with FuelMaker systems, and some NGV manufacturers have set up incentives for their use (e.g., Honda sales of its Civic GX).

Electricity Demand, Supply and Price

The cost of electricity in California depends on local utility rates and other factors. For EV charging, there are a variety of rate structures. Residential EV charging rates currently range from $.04 to $.12 per kWh for off-peak charging, with on-peak charging costing substantially more. Also, electricity prices and charging costs change with the seasons and additional time-of-use and demand charges may be applied. To take full advantage of special off-peak EV charging rates, residential customers may need to install a second meter or a dual-meter adapter. As an example, the Sacramento Municipal Utility District (SMUD) offers an EV charging rate that is approximately half the regular residential rate. To take advantage of the EV charging rate, SMUD requires that an additional meter with a dedicated EV charging outlet be installed at the residence.

Figure 4-15 shows the historic average of electricity rates in California for residential and commercial customers from 1975 to 1998. Since electricity restructuring took effect in 1998, significant changes have been occurring in the supply and pricing of electricity. During late 2000, the supply of electricity in California reached near-crisis levels and several emergencies were declared, even though demand was significantly lower than that of the summer peaks. This problem resulted from complex factors related to deregulation, and emergency steps are being taken to resolve the crisis (as previously described). As of March 2001, the related issues of electricity supply, demand and price persist as a major crisis for California. Forecasts indicate that "rolling blackouts" due to insufficient supply will likely persist until new power plants come on line.

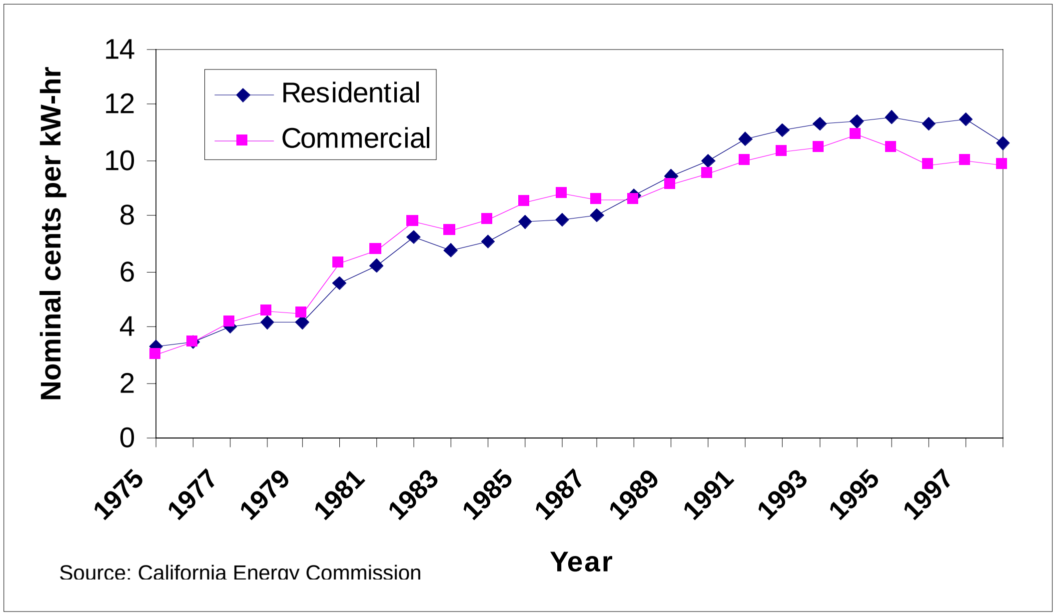


Figure 4-15. Historic avg. electricity rates (residential and commercial) for California, 1975-1998

On March 27, 2001, the California Public Utilities Commission unanimously approved an immediate increase in electricity rates, by as much as 42% in Southern California and 46% in

Northern California. The rate hike is targeted towards easing California's ongoing power crisis and avoiding blackouts during peak-usage summer months. However, as of the writing of this report, serious concerns are being expressed that it will not solve the fundamental problem of increasing wholesale electricity prices.[116]

California's current power crisis is urgently being addressed by many agencies at the highest local, state and national levels. Its full ramifications to the Clean Fuels Infrastructure Development Plan are not clear. On the one hand, at the level of deployment envisioned by CARB, the anticipated amounts of electricity needed to recharge EVs in California over the next decade are not expected to significantly impact supply and demand issues. On the other hand, if high electricity prices and localized supply disruptions persist into 2003, this may negatively impact consumer choice about purchasing EVs, for those who are depending on the convenience of on-peak day charging. In lieu of these concerns, it is recommended that further assessments be conducted on California's EV market and the corresponding need to develop charging stations, before further consideration is given to using the Energy Commission's infrastructure development funds for this purpose. Specific recommendations are provided at the end of this section.

Capital Cost of EV Charging Stations

The cost of non-residential EV charging stations can vary significantly. A typical Level II inductive charger currently costs about $2,200, while a comparable conductive charger costs from $800 to $2,100 (not including mounting hardware and shipping).[117] The total cost including installation at a new construction site (i.e., where cable and conduit can be laid during the building process) ranges from $5,000 to $7,000. Total costs as high as $10,000 can result in situations where a charger must be retrofitted at an existing site, or if long trenches are needed to hook up with the source of electricity.[118] Significant cost reductions can be realized when multiple chargers are installed at the same site.

The current cost of a residential charging station including installation is approximately $1,500. According to estimates cited by CARB in recent ZEV documents, this cost could be reduced by about 50% over the next several years. An example of how costs can be reduced is passing of a local ordinance requiring new housing construction to include 220V wiring to an electrical panel in the garage. Several cities in both northern and southern California already have such an ordinance. This reportedly costs as little as $5 extra during the construction process, where it could cost about $200 to retroactively add a new panel in the garage.

According to the California Electric Transportation Coalition, station owners have paid between 25% and 60% of the costs for public charging stations. In other situations such as fleet and retail EV use, infrastructure costs are correlated to the purchase or lease of EVs. Cost sharing to assist owners and operators is available on a limited basis. The Energy Commission offers the only current cost-share program for EV charging; this offers matching

[116]Source: The Los Angeles Times, "Largest Rate Increase in State's History Approved," March 28,2001, from website (http://www.latimes.com). Note: no information was available directly from the CPUC website on this action.

[117] California Air Resources Board, ZEV Infrastructure: A Report on Infrastructure for Zero-Emission Vehicles, January 2001.

[118] According to survey input from CalETC.

funds from the Petroleum Violation Escrow Account (PVEA) and participating automakers to help buy down capital costs and installation. Over the last several years, there have been other programs throughout the state funded by the U. S. DOE Clean Cities Grant Program and the Mobile Source Air Pollution Reduction Review Committee.

Station Operation, Maintenance and Training

EV charging stations are easy to operate and require no maintenance on the part of the end user.

Public Access: Hours and Accommodations

Hours of access to public charging stations vary. As a general rule, stations are available during the operating hours of the host site. Most public EV charging stations found in parking lots are available 24 hours. In the case of garages, operating hours are usually linked to working hours, e.g., 6:00 a.m. until 8:00 p.m.

Presently, EV charging is free to the user at public stations because the host site pays for the electricity. Thus, card reader access and point-of-sale billing are not yet issues. Edison EV reportedly proposed a billing demonstration program, but it was never implemented. Some billing system and card system mechanisms have been tested, e.g., the Bay Area Rapid Transit's kiosk charging system. Development of user-friendly and cost-effective card reader systems for EV charging will become a priority as greater numbers of EVs are deployed over the next several years.[119]

Building Codes and Standards

EV charging stations must meet Article 625 of the 1996 California Electric Code. Building codes determine how the electrical code is implemented and set the standard for permit approval. In addition, EV charging stations must meet Interim Disabled Access Guidelines issued by the California State Architect's Division – the only fueling station type required to do so.[120] These existing standards and codes are updated as needed, based on technology changes and other factors.

Time Horizon for Full Technological Maturity

With California's ZEV requirement recently upheld by CARB, it appears that thousands of new EVs will be deployed beginning with the 2003 model year. Consequently, more charging stations will be needed throughout California at publicly accessible sites such as shopping malls, transportation hubs, private companies, and government facilities. To insure EV charging locations do not become stranded investments, specific identification of existing EVs and typical EV owner's driving patterns must be assessed including projections of future EV growth patterns and related EV electricity supply/demand issues. Table 45 summarizes input from the TAG regarding their prognosis for full commercialization of EVs and the corresponding charging infrastructure.

[119] According to survey input from CalETC.

[120] Survey input from CalETC and the Clean FuelConnection, Inc.

As this information suggests, the time horizon for full technological maturity of battery EVs (and the corresponding infrastructure of charging stations) depends on complex and/or unknown factors. CARB's newly adopted modifications to the ZEV regulations will allow greater flexibility for automakers to meet part of their ZEV obligations with other types of ultra-clean vehicle technologies. This modification could reduce the rate of progress towards full technological maturity for battery EVs, and deployment of charging stations. In addition, automakers are pursuing other types of "pure ZEV" technologies" over the longer term (e.g., see Section 3.2.2. Hydrogen Fuel Cell Vehicles) that may out-compete battery EVs in the marketplace. While it's too soon to fully evaluate the impact of these factors, projections from CARB indicate that annual production of battery EVs for the California market will be in the tens of thousands beginning in 2003.

Table 45. Summarized survey response on long-term horizon for EV charging

Issue	Response
Expected Timeframe for Full Commercialization	♦ Complex –- depends on many factors[121]
Needed actions and activities to achieve	♦ Easy access to public charging ♦ Approximately 3 chargers per driver—one at home, one at work and several public locations ♦ More workplace charging and public charging in No. California to stimulate customer demand for vehicles ♦ "Corridor charging" to enable EV travel from No. CA to So. CA ♦ Low-cost durable unattended system for point of sale and shared car reservation ♦ Demonstrations / reporting of fleet fast charging, retail fast charging, and fleet sequential charging ♦ Expanded capacity to charge at high-demand stations such as airports ♦ Common connector standard instead of inductive and conductive ♦ Long-term statewide infrastructure plan, as more EVs are deployed
Existing methods of financing EV charging stations and activities above	♦ Funding sources such as the Energy Commission, local APCDs and participating automakers provide 40% to 75% of the cost for individual stations ♦ Government and industry sources to cost share a program that graduates the % of cost share by infrastructure priorities.
New financial incentives and / or administrative actions needed to overcome barriers	♦ Develop a workplace charger program with meaningful credit (i.e., rideshare) to employers for installing infrastructure. ♦ Significant cofunding (at least 50%) is needed at the initial stages of the market for installation of charging at workplaces and good public locations i.e., shopping malls, entertainment venues. ♦ Financial incentives for installation of charging in new commercial construction (i.e., developer installs conduit and incentive program pays for chargers and installation). ♦ Better "packaging" and selling of incentives to potential end users. Focus on simplicity and strong outreach to public and private fleets. ♦ Availability of conveniently located work parking (Green Vehicle Parking).

However, the types and numbers of vehicles that are ultimately produced and deployed will drive California's long-term expansion of the EV charging network. Variables that will affect charging infrastructure needs include: 1) the mix of battery types used, and their range capabilities, 2) the mix of EV types by size and use characteristics (e.g., city EVs, low-speed

[121] When survey responses were received, EV production scenarios were less certain due to a potential rollback of the ZEV mandate. Since that time, CARB voted to maintain the mandate, while allowing greater flexibility to automakers in meeting ZEV obligations.

vehicles, full-sized sedan EVs, utility EVs), 3) the mix of EVs by owner type (fleets vs. private individuals), 4) predominance of fast charging, and 5) potential emergence of plug-in hybrids that don't entail deep discharge.

Summary of Major Barriers and Impediments for EV Infrastructure

There are a number of key barriers and impediments for expansion of the EV charging infrastructure in California. These include the following:

- California's ongoing energy crisis and potential competing demand for electricity makes day charging availability (on-peak) less likely.
- Lack of EV products (e.g. batteries), especially from the major automakers
- Past incentives are now being phased out; continued funding is needed in the early stages of the EV market
- Resistance from employers to install workplace chargers (e.g., it can be viewed as a special privilege for a few employees, or a fuel subsidy that others can't receive)
- Meaningful incentives for workplace charging are lacking; current Federal tax deductions are not viewed as significant, as are trip-reduction credits for large employers
- Lack of a current charger standard results in fleets installing conductive and inductive chargers, which is expensive
- Competition from other vehicle technologies either becoming commercially available or meeting or nearing ZEV standards (e.g. fuel cell technologies, hybrids).

As a result of the most recent biennial review on the ZEV program, CARB staff released a report assessing and addressing some of these barriers for the EV charging infrastructure. The report provided background on the status of public charging, EV charging technologies, safety standards related to EV infrastructure, infrastructure costs, and incentive programs related to infrastructure as well as recommendations for charger standardization. One broad recommendation was to establish a stakeholder-based EV infrastructure working group. Additional, more specific recommendations are summarized in Table 46.

Table 46. CARB staff report recommendations on EV infrastructure

Barrier / Issue	Recommendation
Lack of single standard for EV charging stations	♦ Work with charging infrastructure industry and automakers to develop and adopt a single charging standard
Limited public charging infrastructure	♦ Expand number of public stations, targeting "most critical" locations and applications
Improper use of EV charging spaces by non-EVs	♦ Develop local ordinances to discourage non-EV parking in spaces designated for EV charging ♦ Encourage enforcement of ordinances
Lack of information for EV users	♦ Develop centralized information center and improved mapping systems for EV users to keep abreast of where to find charging stations
Lack of EV charging stations at work locations	♦ Offer greater incentives and grants for employers to install EV charging stations ♦ Initially target locations having existing EV users as employees
Need for new / improved EV incentives	♦ Work with stakeholders to review effectiveness of existing incentives, and develop new incentives as needed
Impact of EV charging on the electricity grid	♦ Establish working group to further evaluate the issue and prepare relevant information
Source: California Air Resources Board, ZEV Infrastructure, January 2001	

Recommendations for Further Assessments on EV Infrastructure

Many EV-related activities are being spearheaded by CARB, individual air districts, the Energy Commission and federal entities. It is recommended that additional research be conducted to assess what level of support, if any, the Energy Commission should allocate for EV infrastructure under the Clean Fuels Infrastructure Development Plan. Key areas to further assess include the following:

- The projected numbers and types of EVs that will be deployed in California for the 2003 to 2010 timeframe, by type and end use (government fleets, private users, utilities, etc.)
- The exact numbers and types of existing EV stations and how they are currently used by end users
- The impact that neighborhood electric vehicles (NEVs) are likely to have on EV infrastructure needs
- The feasibility of adopting statewide ordinances that require construction of new homes and businesses to be compatible with state-of-the-art EV charging systems
- The potential to develop and deploy an effective, affordable billing system for public EV charging stations
- The development of fast charging systems capable of fully charging EVs in comparable time to that of liquid or gaseous fueling systems.

4.5 E85 Fuel and Fueling Stations

Number of Stations in California

Thousands of E85 FFVs built by several automakers are currently being operated in California (refer back to section 3.1.4 on page 32 for a list of available models). The FFV feature is standard equipment for these particular makes and models. For example, every 2000 MY 3.0 Liter Ford Taurus LX, SE, SES Sedan and SE Wagon sold in California (and throughout America) is an FFV. Although these vehicles were designed to operate on E85 or any mixture of E85 and gasoline, there are currently no E85 stations in California. This means that virtually all E85 FFVs in California are being operated on gasoline.

However, E85 stations do exist in other states. Since corn is a primary feedstock for ethanol, it's not surprising that America's highest concentration of E85 use and fueling stations is in the Midwest. According to the Alternative Fuels Data Center, there are between 41 and 60 stations located in Wisconsin, while numerous states have at least one station.

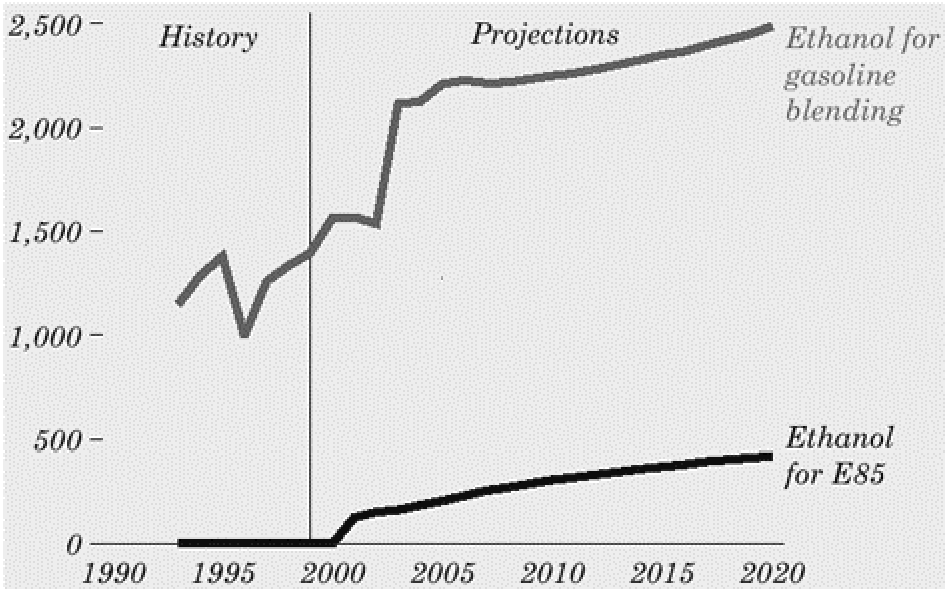
Existing and Needed Fuel Throughput

No response to the fueling infrastructure survey was received from the ethanol industry. Therefore, it is unknown how many E85 stations are needed to develop a self-sustaining E85 infrastructure in California, or the corresponding fuel throughput at each station.

Fuel Supply, Demand and Price

U.S. fuel grade ethanol production reached 1.5 billion gallons in 1999, with corn serving as the primary feedstock. Demand in the same year was approximately 1.35 billion gallons.[122] Most of this was consumed in the transportation market through ethanol's use as a blending agent with gasoline, either to extend volumes of gasoline, or increase oxygenate levels to reduce wintertime carbon monoxide emissions from vehicles. Used in these ways, ethanol is considered a "replacement" fuel instead of an alternative fuel (per the U.S. Energy Policy Act). As Figure 4-16 shows, between 1.0 and 1.5 billion gallons of ethanol per year were blended into U.S. gasoline stock over the last several years; most of the resulting blend was sold in Midwest markets as so-called "gasohol." The federal Energy Information Administration projects that by 2020, the use of ethanol for gasohol or as an oxygenate will grow to about 2.5 billion gallons per year. This projection includes an increase in the expected role of ethanol as the preferred oxygenate for reformulated gasoline, since California and seven other states have passed legislation limiting or banning the use of methyl tertiary butyl ether (MTBE).

[122] Energy Information Administration, Energy Outlook 2001, December 22, 2000.



Source: Energy Information Administration, Energy Outlook 2001, December 22, 2000.

Figure 4-16. Past and projected U.S. ethanol consumption (millions of gallons)

The lower curve in Figure 4-16 shows the past and projected consumption trends nationwide for ethanol used to make E85 fuel for FFVs (see Section 3.1.4). Use of ethanol to make E85 has been very low compared to its use in gasohol. However, the federal Energy Information Administration projects that the U.S. demand for E85 will grow significantly over the next 20 years, and reach nearly 500 million gallons in 2020.[123]

Because ethanol is the only approved oxygenate to replace MTBE in California, demand for ethanol in California (for all transportation applications) could exceed 700 millions gallons a year, or about 40 percent of the nation's current total output, when MTBE is phased out of California's gasoline supply by 2003.[124] A recent Consultant Report for the Energy Commission evaluated the costs and benefits of using biomass-based ethanol production in California to meet this oxygenate demand for California gasoline. The analysis was based on establishing 200 million gallons per year of ethanol production in California. Many positive attributes were identified to establishing a biomass-to-ethanol industry in California, including a finding that the economic benefits are potentially greater than the costs.[125]

Currently, in those states where it can be purchased, E85 is more expensive than gasoline on an energy-content basis. Details on the cost and price dynamics of E85 were not available from the ethanol industry,[126] but a spot check of three stations in the Midwest (March 2001) indicated that E85 prices at the pump range between $1.40 and $1.60 per gallon. This is

[123] Presumably, all this E85 would be used to fuel FFVs, since there are currently no other mainstream uses for E85, and E-100 will be needed if ethanol is to be used in fuel cell vehicles.

[124] California Energy Commission, press release, Report Says California Can Benefit from Biomass-Based Ethanol Industry, March 21, 2001.

[125] California Energy Commission, Costs and Benefits of a Biomass-to-Ethanol Production Industry in California, Draft Final Consultants Report P500-01-002, by Arthur D. Little, March 2001, at http://www.energy.ca.gov/mtbe/ethanol/index.html

[126] No survey response was received from the ethanol interest on the TAG.

equivalent to between $1.96 and $2.24 per gallon on an energy-content basis with gasoline.[127]

Beginning in 2003, as MTBE is phased out and ethanol is used as its substitute, there will be a major increase in demand before new ethanol production facilities can come on line in California. This will likely cause a significant increase in the price of ethanol, causing the price of E85 to approach or exceed $2.00 per gallon.[128] In essence, the use of ethanol for E85 to fuel FFVs would have to compete with its need as an oxygenate for reformulated gasoline. This issue further clouds the future potential of ethanol to displace significant volumes of petroleum fuel in California. Clearly, the use of ethanol in California as a gasoline blending agent for motor vehicles will increase over the next 20 years, but currently there is no foreseeable path to commercialization for near-neat (E85) or neat (E-100) ethanol.

Building Codes and Standards

E85 stations must meet similar codes and standards as M85 stations, although the fuel is less corrosive and therefore creates fewer materials-compatibility issues. A good source for codes, standards and other issues associated with E85 stations is Guidebook for Handling, Storing and Dispensing Fuel Ethanol, prepared by the U.S. Department of Energy (see http://www.afdc.nrel.gov/pdfs/ethguide.pdf).

Time Horizon for Full Technological Maturity

E85 stations are already technologically mature, in those states where they are currently located.

Summary of Major Barriers and Impediments

There are a number of key barriers and impediments for the E85 fueling infrastructure in California. These include the following:

- High production and distribution costs relative to gasoline and diesel fuel.
- Lack of dedicated ethanol-fueled vehicles
- Lack of a fuel-use requirement in the federal Energy Policy Act.
- Lack of a fuel-use requirement in federal Corporate Average Fuel Economy regulations.
- Lack of ease moving ethanol through the existing petroleum product network to end-users.[129]
- Greater demand and more favorable economics to use ethanol as an oxygenate in reformulated gasoline

[127] A gallon of E85 contains about 71% of the energy found in a gasoline gallon.

[128] California Energy Commission, Costs and Benefits of a Biomass-to-Ethanol Production Industry in California, Draft Final Consultants Report P500-01-002, by Arthur D. Little, March 2001, at http://www.energy.ca.gov/mtbe/ethanol/index.html

[129] Source - http://www.afdc.doe.gov/altfuel/eth_general.html

4.6 Methanol Fuel and Fueling Stations

Number of Stations in California

Methanol is a liquid fuel made from natural gas or renewable biomass resources. At its peak use, M85 fuel (85% methanol blended with 15% gasoline) was sold at more than 60 facilities around California, most of which were public-access stations. During the same period, several transit districts converted one or more on-site diesel pumps over to neat methanol (M100) stations. Most notably, the Los Angeles County Metropolitan Transit Authority operated several M100 facilities to fuel approximately 330 methanol buses (equipped with Detroit Diesel 6V92 engines). The Energy Commission developed a "California Fuel Methanol Reserve," and entered into cooperative agreements with certain oil companies to dispense competitively priced methanol for at least 10 years. However, with no certified methanol vehicles on the market today, only a fraction of California's M85 and M100 fueling stations remain operational.

Being an excellent carrier of hydrogen for fuel cell applications, methanol may re-emerge as a transportation fuel in California. Based on announcements made through the California Fuel Cell Partnership and by individual automakers,[130] it appears possible that within a decade significant numbers of light- and heavy-duty vehicles will be powered by fuel cell engines using methanol[131] reformate. Methanol producers expect to be able to meet the fuel demand if these fuel cell vehicles come into widespread use. However, there will be many retail-level issues to resolve. The most likely scenario for developing a methanol fuel distribution system would be similar to what already occurred in the 1980s and early 1990s -- utilizing the existing gasoline distribution system by adding methanol-fueling capacity to retail gasoline outlets. This would require making sure that station components such as storage tanks, piping and dispensers are methanol compatible.[132]

Existing and Needed Fuel Throughput

Methanex Corporation, a global leader in methanol production and marketing, estimates that widespread acceptance of methanol fuel cell vehicles will require about 10% of California's fueling facilities dispensing the fuel. This would roughly equate to 950 methanol stations statewide. Locations of these stations would need to be coordinated with the heaviest concentrations of fuel cell vehicles, i.e., in the Los Angeles, Sacramento, San Diego, and San Francisco metropolitan areas. Methanex indicated that "many factors must be considered to estimate the fuel volumes per station," including number of user vehicles, geography and distribution system efficiency.[133]

[130] The automaker most aggressive in making such announcements has been Daimler Chrysler, which has indicated that it will commercially introduce methanol-fueled FCVs by 2002 (see http://www.daimlerchrysler.com/index_e.htm?/news/top/2000/t00619_e.htm).

[131] Methanol would have to compete with other "hydrogen carrier" fuels, possibly including gasoline, with its fully developed fueling infrastructure.

[132] Most underground tanks in the greater Los Angeles area are already methanol-compatible, due to SCAQMD Rule 1170, which requires that "at least one tank be compatible when one or more underground motor vehicle fuel storage tanks are installed or replaced."

[133] Survey response from Methanex Corporation, October 2000.

Methanol Supply, Demand and Price

Methanol is sold as a chemical commodity and priced accordingly. According to industry consultant Chemical Market Associates Inc., US Gulf Coast spot pricing for methanol in March 2001 were at $233 to $238 per tonne (or 70 to 71.5 cents per gallon). As of March 30, 2001, spot pricing of methanol in the Asia/Pacific region was between 57 and 69 cents per gallon, depending on location. Methanex reports that its average realized price for methanol increased from $105 per tonne (32 cents per gallon) in 1999 to $160 per tonne (48 cents per gallon) in 2000.[134] On an energy basis, this latter price ($0.48) is equivalent to gasoline at about $1.00 per gallon.[135] The long-term price of methanol (2010 time frame) will be a function of many factors (e.g., the cost of natural gas feedstock, methanol surpluses resulting from MTBE phase-out), but projections from government sources indicate that it should be competitive with gasoline on an energy equivalent basis.[136]

As previously noted, a consortium has been established to determine methanol fuel specifications for fuel cell vehicles. Additionally, testing of fuel cell systems is being conducted using various grades and combinations of methanol, and potential fuel additives. These results will be utilized in determining the quality of methanol fuel that must be delivered to fuel cell vehicles.

Station Capital Costs

Based on the M-85 station experience in California, the next-generation of methanol stations (i.e., M-100 most likely focused on fuel cell vehicle applications) will be very similar to today's gasoline fueling stations, having the same layout and employing the same types of equipment. However, before M-100 can be dispensed as a commercial fuel for vehicles, a number of safety and logistical issues will need to be addressed. These include: lack of flame luminosity, safety of flammable vapors in storage tanks, prevention of ingestion, safe handling by the public in a self-serve environment, and managing corporate liability.

According to a 1999 study performed for the methanol industry by EA Engineering, Science, and Technology, Inc., the capital cost of adding methanol storage and dispensing capabilities to an existing gasoline station is about $62,400. This retrofit consists of installing a new double-walled underground storage tank, and methanol-compatible components such as product and vapor piping, dispensers and valves. Where space is available and local codes allow, an above-ground tank can be installed, reducing the overall cost to around $54,600.[137] If an existing gasoline or diesel underground tank is already double walled and methanol

[134] From Methanex Corporation website (http://www.methanex.com/methanol/currentprice.htm).

[135] Methanol contains about 57,000 btu/gal, while gasoline contains about 115,000 btu/gal (both LHVs).

[136] National Renewable Energy Laboratory, Alternative Fuels Data Center, website (http://www.afdc.nrel.gov/altfuel/met_general.html).

[137] Much of this information was obtained from “Methanol Refueling Station Costs,” prepared for the American Methanol Foundation, by EA Engineering, Science, and Technology, Inc., February 1999.

compatible,[138] it can be cleaned and converted for methanol storage. This lower-cost option would still require installing methanol-compatible piping and dispenser equipment.

Time Horizon for Full Technological Maturity

The strongest indications that commercial "re-deployment' of methanol fueling stations may occur in California over the next five to 10 years are the methanol-related activities of the California Fuel Cell Partnership and its individual members. One associate member of the Partnership, Methanex Corporation, is a member of the Energy Commission's TAG, and responded in October 2000 to the Clean Fuels Market Assessment's fueling infrastructure survey. Table 47 summarizes key input received from Methanex.

Table 47. Summary of survey input from Methanex on methanol infrastructure

Expected Timeframe for Full Commercialization	Number of Methanol Stations Needed in California	RD&D Activities and Plans
♦ No estimate given for full commercialization of methanol fuel cell vehicles or corresponding fueling infrastructure ♦ Initial deployments expected in 2004.	♦ Approximately 10% of today's retail fueling stations for vehicles ♦ Level of throughput needed at each station for commercial success depends on many factors	♦ Associate member of the California Fuel Cell Partnership ♦ Partnership will demonstrate different types of FCVs in the Sacramento area and "appropriate refueling mechanisms" in 2002 and 2003 timeframe ♦ Also supporting fuel cell demonstration activities in Europe and Japan ♦ Co-operative agreement with Statoil and XCELLSIS to evaluate commercialization needs

Methanol Infrastructure RD&D Activities

Through its involvement in the California Fuel Cell Partnership, the methanol industry is involved in efforts to prepare for deployment of fueling stations to meet the fuel demands of fuel cell vehicles as they are deployed. For example, Methanex Corporation, Statoil and XCELLSiS[139] recently announced a co-operative agreement to evaluate how to commercialize methanol fuel cell vehicles. Under this agreement, health, safety, environmental and infrastructure issues associated with the use and introduction of methanol fuel cell vehicles will be evaluated. According to the press release, these parties will publish the findings and "expect to implement their findings in a real world application in the near future."[140]

[138] This is the case for most underground tanks in the greater Los Angeles area. Since 1988, SCAQMD Rule 1170 has required that "at least one tank be methanol-compatible when one or more underground motor vehicle fuel storage tanks are installed or replaced."

[139] XCELLSiS, formerly known as DBB Fuel Cell Engines, is a collaboration between Daimler-Chrysler, Ballard Power Systems and Ford to build and deploy fuel cell engines with electric drive systems.

[140] From XCELLSiS website (www.xcellsis.com).

Summary of Major Barriers and Impediments

Currently, there are less than ten public methanol stations in California, and possibly several stations operating for private-fleet applications. The biggest barrier to a resurgence of California's methanol infrastructure is that no major vehicle manufacturers are currently selling on-road vehicles that use methanol fuel.[141] This situation may change over the next several years, since several major auto manufacturers have announced plans to sell fuel cell vehicles by 2004. If methanol becomes a preferred fuel for such vehicles in California, as is the stated intention of some fuel cell makers and vehicle manufacturers, methanol stations will be needed in proportion to the number of fuel cell vehicles deployed. Methanex estimates that up to 1,000 neat methanol stations will be needed in California to support the early years of commercialization. The California Fuel Cell Partnership includes participation by organizations with vested interests in building methanol stations for this purpose, but it remains to be seen if and when a methanol infrastructure will come to fruition.

4.7 Hydrogen Fuel and Fueling Stations

Number of Stations

As of early 2001, there are only a few facilities in California that are specifically designed to dispense hydrogen as a motor vehicle fuel. Examples include the two different systems used by Sunline Transit to fuel its direct-hydrogen fuel cell bus in the Coachella Valley. Today's hydrogen stations for vehicle applications are essentially hand-built, first-generation prototypes. Most likely, they bear little resemblance to how optimized, cost-competitive hydrogen stations of the future may perhaps operate.

Existing and Needed Fuel Throughput

Throughput at the few existing stations in California that dispense hydrogen fuel for vehicles is very small, and currently insignificant in terms of petroleum fuel displacement. Although estimates have been made for numbers of direct-hydrogen fuel cell vehicles in California over the next decade (see page 35), it is premature to determine the necessary volumes of hydrogen needed to sustain a hydrogen fueling infrastructure in California.

Hydrogen Supply, Demand and Price

Hydrogen, the simplest and lightest fuel, is the most abundant element on earth. However, hydrogen normally occurs in a bound state with other elements and requires relatively large amounts of energy to extract it from compounds such as water and natural gas. Hydrogen is considered a renewable energy source, and supply is not expected to be a problem, at least in terms of available feedstocks.

Because hydrogen is in a gaseous state at atmospheric pressure and ambient temperatures, its use as a transportation fuel presents greater transportation and storage challenges than liquid fuels. Similar to the case with natural gas fuel, there are a variety of approaches used to produce hydrogen and store it onboard vehicles. These include the following:

[141] It is noteworthy that the various types of E85 FFVs currently available in California use similar technology as formerly available M85 FFVs. Reintroduction of M85 FFVs to the California market would not involve major changes in vehicle hardware or software.

- Off-site steam methane reforming of natural gas, with tanker-truck delivery of liquid hydrogen to the refueling station, and on-site storage of liquid and gaseous hydrogen
- On-site natural gas reforming, with on-site compression and storage of gaseous hydrogen
- On-site electrolysis (splitting of water into hydrogen and oxygen), with on-site compression and storage of gaseous hydrogen

The "best" method for vehicle applications is yet to be determined and depends on the intended application, as well as many other factors. As noted discussed in Section 3.2.2, the first commercial direct-hydrogen fuel cell vehicles in California are likely to be transit buses, deployed at transit districts that have chosen the "diesel" path under CARB's transit bus fleet regulation. Transit agencies that deploy a small number of fuel cell buses may choose to follow the Chicago Transit Authority model, i.e., where liquid hydrogen is produced at a large centralized plant, and then trucked to the transit agency's on-site fueling facility for storage. Liquid hydrogen is then pumped and vaporized for storage on the bus, similar to the process used on today's LNG vehicles where onboard LNG is vaporized for engine use.

A second alternative would be to follow British Columbia Transit's model, and use on-site electrolysis to produce hydrogen. This option makes most sense if there is an abundance of renewable energy to power the electrolysis process, as is the case in British Columbia (hydro-electric power) and the Coachella Valley of Southern California (wind and solar power). For the electrolysis option, as the hydrogen is generated it is compressed and pumped into storage tanks on each fuel cell bus. Another possibility would be to use on-site generation of hydrogen using a small-scale methane reformer. Both of these latter methods for generating hydrogen are being demonstrated at Sunline Transit in Palm Desert, California, in conjunction with the California Fuel Cell Partnership.

Regardless of how it is produced, hydrogen for fuel cell applications needs to be free of impurities (e.g., sulfur). Fuel standards will need to be adopted before significant numbers of fuel cell vehicles are deployed.

Hydrogen cost and pricing studies have been performed by a variety of entities, including but not limited to Directed Technologies and Princeton University.[142] The price of hydrogen as an automotive fuel will be a function of many factors, including the following: 1) cost of feedstocks such as natural gas and methanol, 2) technology and related costs for the fuel production process (e.g., methane steam reforming, solar electrolysis, hydroelectric electrolysis), 3) proximity of feedstock supply, and 4) specific issues within individual markets served. It is generally accepted that the price of hydrogen fuel will be significantly higher than gasoline and diesel fuel in the early years of fuel cell vehicle deployment.

Station Capital and Operational Costs

The capital costs of hydrogen stations are not fully known at this time. Station designs are only in the conceptual stage, and few hydrogen-specific codes and standards exist. Capital

[142] For example: J.M. Ogden, "Developing a Refueling Infrastructure for Hydrogen Vehicles: A Southern California Case Study," International Journal of Hydrogen Energy, 1999, and J.M. Ogden, M. Steinburler and T. Kreutz, "A Comparison of Hydrogen, Methanol and Gasoline as Fuels for Fuel Cell Vehicles," Journal of Power Sources, vol. 79, pp. 143-168, 1999.

costs will depend in part on whether a liquefied hydrogen or compressed form of hydrogen will be stored and/or produced at the station. In either case, costly fire and safety requirements are likely to be the norm at hydrogen stations in the early years of deployment. In 1998, it was estimated that the costs of hydrogen fueling stations for a typical 200-bus transit operation would likely exceed the current cost of large CNG stations (i.e., as much as $1.5 million).[143] Recent estimates for first-generation hydrogen stations being built in West Sacramento and other areas under the California Fuel Cell Partnership indicate they can cost between $2 and $3 million, at least in these early developmental years.[144] Given that a large LNG station for transit bus operations can cost as much as $4.5 million when including all necessary site modifications,[145] it's possible that comparably sized hydrogen stations will carry even higher price tags initially.

Operation and maintenance costs for hydrogen stations are also likely to be as high or higher than comparable types of natural gas stations (i.e., compressed or liquefied gas).

Building Codes and Standards

Few (or no) standards and codes have been established specifically for hydrogen vehicle fueling stations. It is expected that certain existing standards for other compressed or liquefied fuels will be adapted for hydrogen; however, entirely new standards and codes will be needed as well. This is one of the most challenging existing barriers to using hydrogen as a mainstream transportation fuel. Recently, government and industry representatives discussed this issue in detail at a "Blueprint for Hydrogen" workshop.[146] A wide array of experts at the workshop assigned high priority to addressing hydrogen safety, along with the accompanying codes and standards.

It was recommended that various federal agencies establish a national entity to prepare and promulgate uniform codes and standards for hydrogen use as a fuel for light-duty vehicles and transit buses. Some of these efforts are under way today through the International Standards Organization's (ISO) Technical Committee (TC197), in conjunction with DOE and the National Hydrogen Association. DOE is also supporting a comprehensive effort to incorporate codes for hydrogen applications through the International Code Council (ICC) process. In addition, this work on hydrogen codes and standards will be coordinated with similar activities sponsored by the European Union. Sound practices for public safety and handling of hydrogen fuel were also emphasized at the workshop, including training for end users such as transit bus districts.

Time Horizon for Full Technological Maturity

As previously noted, a good source of information about hydrogen fuel for automotive applications is entitled *Blueprint for Hydrogen Fuel Infrastructure Development*,[147] which

[143] Source: based on Table 41 of Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Options, Transportation Cooperative Research Program Report 38, Transportation Research Board, National Academy Press, 1998

[144] Personal communications to Jon Leonard (Arthur D. Little) from Susan Brown and Ken Koyama (California Energy Commission), 02/01/01.

[145] This was the case with OCTA's Garden Grove LNG facility (see LNG station section).

[146] Blueprint for Hydrogen Fuel Infrastructure Development, Jim Ohi, National Renewable Energy Laboratory, based on October 1999 workshop cosponsored by US DOE, California Energy Commission, and the California Air Resources Board.

[147] Blueprint for Hydrogen Fuel Infrastructure Development.

summarizes results of a workshop co-sponsored by the U.S. Department of Energy, the California Air Resources Board, and the Energy Commission. The main objective of the workshop was to assess immediate actions needed to develop the beginnings of a hydrogen fuel infrastructure within three to five years (i.e., the stated timeframe for the first hydrogen fuel cell vehicles in California). This Blueprint documents a consensus among industry and government participants on the desirable attributes of a hydrogen fuel infrastructure, and provides estimates of the number, type, and uses of hydrogen vehicles anticipated in the 2000–2005 time period. It also explores how addressing near-term requirements and barriers will facilitate establishment of a commercial-scale hydrogen fuel infrastructure.

Among the conclusions of the workshop was a consensus that the auto and energy industries see no apparent "show stoppers" for technological advancement of hydrogen fueling stations or fuel cell vehicles that might prevent significant deployment of hydrogen vehicles over the next five years. In the words of the Blueprint for Hydrogen report, "the issue here is timing and coordination of capital investments."[148] However, the magnitude of needed funding is very large, with few compelling reasons for private industry to make such investments, as long as petroleum fuels are abundant and affordable to the motoring public.

Hydrogen Infrastructure RD&D

To address these two major issues of funding and timing, recommendations emerged from the workshop to develop a roadmap for a commercial-scale hydrogen fuel infrastructure. While this will be a national and even international collaboration of government and industry partners, California is clearly the focal point.

[148] Blueprint for Hydrogen Fuel Infrastructure Development.

Table 48 summarizes the priorities for hydrogen RD&D that were identified, and the aggressive schedule for implementation. Major funding appropriations are expected to come from DOE and other federal agencies, with cost sharing from industry and government partners.

Table 48. Schedule of tasks for the "Blueprint for Hydrogen" RD&D plan

Task	2000	2001	2002	2003	2004	2005
Standardized Dispensing Station Design	Establish requirements, draft/validate design, standardize dispensers and other key components	Adopt and promulgate design	Install initial dispensing stations	Original equipment manufacturers (OEMs) build standard dispensing equipment	Build dispensing stations as needed	Build dispensing stations as needed
Test and Certify Hydrogen Containers	Adopt test requirements, conduct testing, certify to DOT standards	Validate container systems on vehicles, begin fleet testing	Define O&M requirements; OEMs begin building containers to certified standards	OEMs build containers to certified standards	OEMs build containers to certified standards	OEMs build containers to certified standards
Integrated Codes and Standards (C&S)	Prepare overall C&S strategy	Submit draft code to ICC	ICC publishes code	Effective date of code	Prepare revision if needed	Submit revisions to ICC
Safety RD&D for Public Use of H2	Prepare and initiate RD&D Plan	Conduct RD&D, training	Conduct RD&D, training	Publish safety and training guidelines	Validate public safety	Start limited public fueling
Roadmap	Core group prepares and adopts Roadmap	Begin to implement Roadmap	Revise Roadmap for longer term	Install initial infrastructure	Validate fleet vehicle refueling	Revise Roadmap

Source: From *Blueprint for Hydrogen Fuel Infrastructure Development*, Jim Ohi, National Renewable Energy Laboratory, based on October 1999 workshop cosponsored by US DOE, California Energy Commission, and the California Air Resources Board.

To obtain further input on hydrogen RD&D, several organizations on the TAG with vested interests in hydrogen were sent the Energy Commission’s clean fuels infrastructure survey in mid 2000. Table 49 summarizes the relevant input that was received from these TAG members regarding priorities for hydrogen RD&D. In several cases there are linkages to the Blueprint RD&D priorities described above.

Table 49. Summarized responses on RD&D for hydrogen infrastructure

TAG Member	Existing Infrastructure RD&D	Priority List for Further RD&D
South Coast AQMD	RFP out for hydrogen station demonstration Ongoing work with California Fuel Cell Partnership	AQMD will give top priority to funding hydrogen infrastructure RD&D involving: • Technology/hardware for the distributed (small-scale) generation, compression, and dispensing of pure hydrogen. • Safety codes and standards development and adoption for hydrogen refueling stations for motor vehicles. • Advanced hydrogen storage to reduce cost and weight while increasing stored hydrogen mass. • Standardization of hydrogen fueling dispensers
California NGV Coalition	Assorted RD&D activities for CNG (that may be applicable to hydrogen stations)	Possible conversion / transfer of CNG station technology to hydrogen station deployment, after 2010
Sunline Transit Agency	Ongoing work with California Fuel Cell Partnership 10 direct hydrogen fuel cell buses, using 500,000 scf of hydrogen per day	Complete hydrogen fueling systems are needed for fuel cell buses

Of particular note in the table above is the recent request for proposals (RFP) for hydrogen infrastructure development, issued by the South Coast AQMD. This effort is outside of the California Fuel Cell Partnership activities, but closely linked. The RFP seeks proposals to install and demonstrate "stand-alone hydrogen refueling stations" within the South Coast Air Basin over an 18-month period. These stations are intended to serve as a distributed hydrogen infrastructure to support those few early-entry hydrogen-fueled vehicles (fuel cell as well as hybrid internal combustion engine).

SCAQMD will require the winner(s) to design, fabricate and integrate their hydrogen refueling system into a compact, easily transportable package. As stand alone units, these skid-mounted, modular systems will perform all the needed functions to deliver high-quality hydrogen fuel (e.g., generation, purification, drying, compression, dispensing, and possibly storage for fast fill). The latest in state-of-the-art hydrogen production technologies will be sought, including steam reforming, partial oxidation (both thermal and catalytic) and water electrolysis. As noted in the RFP, "steam reforming and partial oxidation could turn existing natural gas distribution pipelines to a distributed hydrogen supply at the dispensing site. Similarly, water electrolysis could rely on electricity and water lines for a distributed hydrogen system."[149]

[149] Information about the SCAQMD RFP was obtained from the corresponding Governing Board letter on the AQMD website (www.aqmd.gov).

Projects such as these have potential to significantly advance the timeline for technological maturity of hydrogen stations in California. However, SCAQMD funding for the project is only $700,000, and much greater levels of funding are needed. These efforts will in part be spearheaded by the California Fuel Cell Partnership. In late 2000, four companies -- Hydrogen Burner Technology, Pacific Gas and Electric, Proton Energy Systems, Inc., and Stuart Energy Systems -- were added to the Partnership. Each will reportedly provide at least one hydrogen fueling station for demonstration in California.[150]

Summary of Major Barriers and Impediments

Major immediate barriers to wide-scale commercialization of hydrogen-fueled vehicles include the following:

- Cost to produce hydrogen
- Lack of commercially available vehicles (internal combustion engine or fuel cell vehicles)
- Lack of low-cost, high-energy-content storage technology for hydrogen
- Lack of capital currently invested in optimized hydrogen fueling stations
- Perception of hydrogen as being more dangerous than conventional fuels
- Need for new codes, standards and safety procedures for the use of hydrogen

[150] Press release, "Four Companies Join California Fuel Cell Partnership To Help Build Hydrogen Fueling Stations," November 10, 2000, from website of the California Fuel Cell Partnership (http://www.fuelcellpartnership.org/).

5. Conclusions and Recommendations

This section summarizes key findings and conclusions, and provides specific recommendations on how to expend the available $6 million under the California Clean Fuels Infrastructure Development Plan ("the Plan").

5.1 Overview and Summary of Target Vehicles / Applications

The Plan targets expansion of fueling infrastructure for alternative-fuel vehicles and applications that will displace the greatest volumes of petroleum fuels. Whenever possible, achieving quantifiable air-quality benefits is also an important objective. In addition to mainstream alternative fuels, a variety of "unconventional" liquid fuels (e.g., biodiesel, Fischer-Tropsch diesel) can potentially help California meet both objectives. However, the immediate infrastructure needs of such fuels are minimal or need further definition, compared to those of the most promising alternative fuels. For the purposes of expending the Plan's available $6 million towards expansion of California's clean fuels infrastructure, candidate fuels assessed in this report include natural gas, propane, ethanol, methanol, electricity and hydrogen. Recommendations for immediate funding allocations are provided for the most pressing fuels and applications; for others, monitoring of progress and/or further assessments are suggested.

Currently, the heavy-duty vehicle sector offers the best opportunities to displace consumption of petroleum fuels and achieve air quality benefits. However, the emissions competitiveness of diesel-fueled HDVs is likely to rapidly improve over the next five years. As such, it's difficult to predict the longer-term degree to which emissions-related regulations will continue to drive AFV commercialization. This makes it even more important to immediately build momentum towards self-sustainable commercial AFV markets, while energy security drivers are complemented by air quality regulations and related incentives. Certain light- and medium-duty vehicle applications that entail high fuel use are also conducive to fuel displacement.

The task to establish sufficient numbers of AFV fueling stations is significant. In the heavy-duty sector alone, tens of thousands of AFVs will potentially be deployed in California over the next decade, either to meet various government regulations or exploit incentive programs. In the greater Los Angeles area, five new fleet rules from the South Coast Air Quality Management District's 1190 Series could potentially deploy more than 16,000 heavy-duty AFVs over the next 15 years. In other parts of California, the California Air Resources Board's newly adopted transit bus fleet rule is already stimulating increased deployments of alternatively fueled transit buses at an estimated 14 transit districts, including large districts in Sacramento, San Diego, and the Bay area.

Near-term alternative fuels that are expected to help displace petroleum fuels in these HDVs include natural gas (CNG, LNG, and L/CNG) and propane. For LNG alone, it is estimated that approximately 6,000 new HDVs and 44 new fueling stations will be needed in the western United States by 2010 to achieve a sustainable vehicle industry. Corresponding vehicle and infrastructure investments will cost an estimated $167 million at the low end, and as much as $334 million. Approximately $4 to $7 million per year will be needed from grants and incentive programs, to augment industry's share (roughly 75%). Large investments in fueling infrastructure are also needed if greater numbers of CNG and propane vehicles are to be deployed.

5.2 California's Energy Crisis and Other Uncertainties

Since mid 2000, California has been experiencing an ongoing, major energy crisis. Virtually all transportation fuel markets have been affected, and new developments are occurring on a daily basis. This report attempts to assess likely ways in which the energy crisis may impact potential AFV infrastructure projects, but comprehensive analysis is not within its scope. The recommendations provided below are based on the assumption that, over the longer run, further investments to diversify fuels in the transportation sector will help alleviate (rather than exacerbate) California's current energy crisis.

A major concern is the rising demand for natural gas by electricity generators, which may severely constrain available natural gas supplies for the transportation sector, and may also further affect supply and price for other key fuels (e.g., propane). Based on the best available information as of mid 2001, it appears that supply and/or distribution problems for alternative fuels such as natural gas and propane will persist in the short term, perpetuating volatile prices that are currently higher than conventional fuels on an energy-equivalent basis. Longer-term supply, demand and pricing scenarios from both the California Energy Commission and federal Energy Information Administration suggest there will be a return to more competitive levels within two to four years.

However, California will need to be proactive in developing new sources for alternative transportation fuels, especially in lieu of the energy crisis. New actions are needed to reduce its ~85% dependency on imported natural gas, currently transported in by pipeline deliveries or LNG shipments that appear fully subscribed. Potential strategies to augment California's supply of clean transportation fuels include further exploiting its large untapped resources of waste-to-energy technologies, and using emerging gas-to-liquids technology to extract stranded reserves of associated natural gas, which can yield LNG, zero-sulfur synthetic diesel fuel, and methanol (among other useful products). These activities are needed in addition to existing efforts to develop small-scale liquefaction plants to produce LNG, using pipeline gas or remote gas sources.

Other concerns when allocating government funds to build alternative fuel infrastructure include: 1) how to avoid "stranded" investments that ultimately fail to help displace significant volumes of petroleum fuels, and 2) establishing criteria to determine when government funds are no longer needed, i.e., developing "exit strategies" for each supported fuel. Uncertainty about these complex issues has been magnified recently due to California's energy crisis. These issues will be tracked and addressed each year as the Clean Fuels Market Assessment is updated. The $6 million that is immediately available for 2001 allocations under the Plan is a relatively small amount, compared to the magnitude of infrastructure investments needed. Using the best-available current information, the recommendations below are focused on the most promising infrastructure deployments that

1) are most in need of government funds to become commercially self-sustaining, and 2) appear to entail the lowest risk to become stranded investments.

Related to this issue of minimizing risk is the question: *To what degree should government-supported alternative fuel stations be required to offer public access and networked card reader systems?* Clearly, major expansion of public-access stations will be needed in the long run to achieve a sustainable AFV market and maximize gasoline and diesel displacement. However, at this early stage of commercialization, stations most conducive to dispensing large volumes of fuel – a critical immediate objective – tend to be private or "limited-access" stations affiliated with large anchor fleets. To address this dichotomy, it is recommended that potential projects and applications be evaluated on a case-by-case basis before determining if public-access capability should be required.

5.3 Funding Recommendations by Vehicle Application

The best use of funds for alternative fuels infrastructure will support end users and vehicle applications with the following characteristics:

- Are motivated by compelling reasons (e.g., regulations and/or incentives) to make alternative fuels work
- Are most in need of government support
- Operate large fleets of centrally housed and fueled vehicles, with a significant percentage of older engines
- Dispense large volumes of fuel
- Can utilize commercially available alternative fuel engines and vehicles, certified to California's lowest applicable emissions standards
- Are located close to other fleets that could share a fueling station[151]

[151] While sharing of stations may make sense from an economic standpoint, logistics to actually make such arrangements can be difficult (e.g., union issues, liability concerns, billing accuracy concerns, etc.).

Fleet applications that generally meet these characteristics, and therefore make the best candidates for high-priority resource allocations in the "large" and "medium" project categories (>$250,000 and up to $250,000, respectively), include the following:

- Refuse haulers
- Transit buses
- Class 8 trucks (return to base)
- High-fuel use LDV applications (e.g., large taxicab fleets)
- High-fuel use MDV applications (e.g., airport shuttle buses, package-delivery services)

There are also potential AFV applications that may not currently involve high fuel use, but are capable of significantly advancing California's long-term potential to displace petroleum fuels. Such applications are good candidates for resource allocations in the "small to medium" category (roughly $65,000 to $250,000 per project). These include:

- School buses
- Small MDV and LDV fleets seeking "startup" operations with dedicated AFVs utilizing a single dispenser, or multiple vehicle refueling appliances (VRAs)

5.4 Recommendations for Specific Resource Allocations by Fuel Type

Taking into account the objectives, issues and criteria discussed above, Table 50 provides specific recommendations for funding allocations towards alternative fuel infrastructure activities. These recommended allocations are meant to be approximate; actual allocations will need to consider many factors, such as vehicle base and throughput, and availability and timing of cost sharing from other sources.

Table 50. Infrastructure activities recommended for highest priority of resource allocations

Station Type	Target Fleets	Specific Needs and Priorities	Approximate Recommended Allocation
LNG	Public and private refuse hauler companies, return-to-base delivery fleets,	• Cost-share new stations • Expand efforts to use small-scale liquefaction facilities and indigenous gas sources to produce LNG in California	~$2.4 Million ~$1.2 Million
CNG	School districts and large, high-fuel-use LDV fleets	• Cost-share new station(s) for school district(s) with highest fuel use and strongest commitment to CNG. Coordinate use of funds for CNG infrastructure with bus purchases under California Lower-Emitting School Bus Replacement Program. • Cost-share new station(s) for taxi fleets or similar-use LDV fleets	~$0.4 Million ~$0.3 Million
L/CNG	Transit districts or private refuse haulers with complement of HDVs and MDVs/LDVs	• Cost-share new L/CNG stations in strategic locations for integrated use of LNG HDVs and CNG MDVs/LDVs	~$1.0 Million
LPG	High-fuel-use State and/or private fleets (including off-road applications)	• Cost-share optimized "beta" LPG stations focused on fleets with dedicated vehicles or large numbers of bi-fuel vehicles that will guarantee fuel use	~$0.5Million
CNG or LPG	Small LDV or MDV fleets starting out with AFVs	• Cost-share sites that can use multiple VRAs or small fueling stations to fuel dedicated AFVs	~$0.2Million
Total of Recommended Resource Allocations			**$6.0 Million**

A goal under the Clean Fuels Infrastructure Development Plan is to achieve approximately $4 of cost sharing for every $1 spent by the Energy Commission. Potential sources to achieve this cost sharing (approximately $24 million) are extensive, as summarized in Table 51.

Table 51. Sources of potential cost sharing

Station Type	Examples of Potential Cost Sharing Sources for Infrastructure / AFVs
LNG and L/CNG	• Turnkey LNG providers • Federal government (per Gas Technology Institute's Infrastructure Working Group recommendations) • ~$7.5 million in MSRC (AB 2766) funds for FY 2001 (partially for infrastructure) • DMV fee programs (AB 2766, SCAQMD Clean Fuels Program) • Consortiums of LDV, MDV and HDV fleets seeking integrated CNG and LNG fueling strategy • Other APCD programs (e.g., up to $70 million from the Sacramento Emergency Clean Air Transportation Program, or SECAT) • ~2.5 million from the Carl Moyer Program – Heavy-Duty Infrastructure Demonstration (requires minimum monthly throughput for new stations of ~10,000 GGE)
CNG	• Turnkey CNG providers • Federal government (per Gas Technology Institute's Infrastructure Working Group recommendations) • ~$7.5 million in MSRC (AB 2766) funds for FY 2001 (partially for infrastructure) • SCAQMD Clean Fuels Program • Other DMV fee programs (AB 2766) • $12 million in SCAQMD funds from recent settlements (Los Angeles metro area) • California's Lower Emitting School Bus Program (new vehicle purchase only) • Other APCD programs (e.g., up to $70 million from the Sacramento Emergency Clean Air Transportation Program, or SECAT) • ~$2.5 million from the Carl Moyer Program – Heavy-Duty Infrastructure Demonstration (requires minimum monthly throughput for new stations of ~10,000 GGE)
LPG	• Turnkey LPG providers (e.g., Clean Fuel USA) • Propane Trade Associations • Petroleum industry • LPG technology and engine developers • ~$7.5 million in MSRC (AB 2766) funds for FY 2001 (partially for infrastructure) • SCAQMD Clean Fuels Program • Other DMV fee programs • Other APCD programs (e.g., up to $70 million from the Sacramento Emergency Clean Air Transportation Program, or SECAT) • ~$2.5 million from the Carl Moyer Program – Heavy-Duty Infrastructure Demonstration (requires minimum monthly throughput for new stations of ~10,000 GGE)

5.5 Recommendations for Further Study and/or Monitoring of Progress

The following recommendations are made regarding other AFV types and their corresponding infrastructure.

5.5.1 Battery EV Recharging Infrastructure

With recent changes adopted in the California ZEV program, it appears that the total number of battery EVs deployed in 2003 will vary from 4,450 to 15,450. This range in part reflects uncertainty about how the modified ZEV program will alter the relative market shares of conventionally fueled light-duty vehicles versus battery-electric vehicles and other clean-fuel technologies.

Today there are nearly 3,300 EV charging stations in California, including approximately 726 private residences wired for EV charging. New stations will be needed as EVs become commercially available, at key locations within metropolitan areas. New activities are underway to assess and address these needs, spearheaded by the Air Resources Board in conjunction with the Energy Commission and local air districts.

The ramifications of California's current power crisis to EV commercialization are not clear, and the potential range of EV numbers that will be deployed is broad. It is recommended that further assessments are conducted before further consideration is given to funding EV infrastructure development under Plan funding. Specific recommendations are as follows:

- An independent assessment should be conducted of the projected numbers and types of EVs that will be deployed in California for the 2003 to 2010 timeframe, by type and end use (government fleets, private users, utilities, etc.)

- An assessment should be conducted of existing EV stations by location, type and how they are used by end users (fleets as well as private individuals)

- An assessment should be conducted on what impact neighborhood electric vehicles (NEVs) will have on EV infrastructure needs (residential and public stations).

- An assessment is needed of the feasibility to adopt statewide ordinances that require construction of new homes and businesses to be compatible with state-of-the-art EV charging systems.

- An assessment is needed of the potential to develop and deploy an effective and affordable billing system for public EV charging stations.

5.5.2 Hybrid Electric Vehicle Infrastructure

Hybrid electric vehicles (HEVs) are being developed that offer the advantages of electric drive (high efficiency and torque at low speeds), while providing performance, fuel economy and range equivalent or better than conventional vehicles. HEV types under development or consideration include grid-connected (plug-in) vehicles as well as those with clean-fueled ICE engines or microturbines. These vehicles have potential to help displace petroleum fuels in the near term as well as serve as a bridge to all-electric propulsion systems (e.g., fuel cells or advanced battery EVs). Since the infrastructure implications are not yet clear, no funding appropriations are recommended at this time specific to HEVs. However, progress should be closely monitored in annual updates of this Clean Fuels Market Assessment.

5.5.3 E85 FFV Infrastructure

FFVs powered by E85 are widely available in California at no incremental cost to the consumer, but currently there are no E85 fueling stations. Virtually all E85 FFVs in California are therefore being operated exclusively on gasoline. Nationally, demand for E85 will grow significantly over the next 20 years, possibly reaching 500 million gallons in 2020. However, there are no known significant plans to sell any of this fuel in California. Plans by vehicle and engine manufacturers to develop and market more advanced ethanol vehicles (e.g., powered by dedicated E100 engines or fuel cells) are also unknown. These are among the key barriers that exist to establishing an E85 or E100 fueling infrastructure in California.

Beginning in 2003, when ethanol replaces MTBE as the oxygenate in California gasoline, there will be a major increase in demand for fuel-grade ethanol. Biomass-based ethanol production in California is one possible means to meet this oxygenate demand, although building new ethanol-production facilities will lag demand. This issue further clouds the future of E85 in California, because the use of ethanol for FFVs is not currently economically competitive with its use as an oxygenate for reformulated gasoline.

For these reasons, it is recommended that no 2001 funds be allocated to ethanol infrastructure under the California Clean Fuels Infrastructure Development Plan. However, future market assessments should revisit this possible use of funds.

5.5.4 Methanol Infrastructure

Methanol is an excellent carrier of hydrogen for use in fuel cells, and can also work well in vehicles with internal combustion engines. Today there are less than 10 public M85 or M100 fueling stations in California. The biggest barrier to expanding this infrastructure is that no major vehicle manufacturers are currently selling on-road vehicles that use methanol fuel. This situation may change over the next several years, since several major auto manufacturers have announced plans to sell fuel cell vehicles by 2004. It is expected that additional information will be released through the California Fuel Cell Partnership, as it becomes available.

Methanol producers such as Methanex expect to be able to meet the fuel demand if these fuel cell vehicles come into widespread use. The most likely scenario for developing a methanol fuel distribution system would be similar to what already occurred in the 1980s and early 1990s -- utilizing the existing gasoline distribution system by adding methanol-fueling capacity to retail gasoline outlets. A consortium has been established to determine methanol fuel specifications for fuel cell vehicles, and assess commercialization issues.

Methanol infrastructure should remain a candidate for potential support under the California Clean Fuels Infrastructure Development Program. However, for the currently available $6,000,000, it is premature to allocate funds to methanol infrastructure.

5.5.5 Hydrogen Infrastructure

Hydrogen is expected to be the long-term fuel for fuel cell vehicles. On strictly a demonstration scale, in certain niche applications such as transit buses, direct-hydrogen fuel cell vehicles are already displacing conventionally fueled vehicles. However, achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production and infrastructure investments of very large proportions. Activities under the California Fuel Cell Partnership and DOE's hydrogen program are addressing some of these issues.

Hydrogen infrastructure should remain a primary candidate for future support under the California Clean Fuels Infrastructure Development Program. However, for the currently available $6,000,000, it is premature to allocate funds to hydrogen infrastructure.

5.6 Recommendations for AFV Infrastructure Incentives

An important ongoing need in advancing the commercial viability of clean fuel technologies is to implement effective, affordable and workable incentives. Until economies of scale can be realized to make alternative fuel technologies self sustaining, manufacturers and consumers need assistance in offsetting higher costs and/or reduced utility compared to conventional vehicles.

Many types of incentives have been used in California and other states to support AFV deployment, but some have clearly been more effective than others. Generally, state and local grants have provided the best motivation for fleets to purchase AFVs, whereas tax credits have worked well for individual AFV owners. In some cases, well-meaning but poorly designed and implemented incentive programs have resulted in ineffective use of funds or even financial disaster (e.g., the Arizona program). Greater understanding is needed on the mechanics of effective incentives for AFVs and fueling stations. It is recommended that the Energy Commission and its partners conduct a detailed assessment of financial and administrative incentives that can most effectively help deploy AFVs with maximum displacement of petroleum fuels. Examples of the types of incentives that could be further assessed are listed in Table 52.

Table 52. Potential new incentives for AFVs and fueling stations

Potential New Financial Incentives	Potential New Administrative Incentives
• Allowance for reimbursement of administrative costs from using clean fuel vehicles and infrastructure • Financial incentives for installation of AFV stations during new commercial construction • More favorable fuel tax laws • Better tax breaks for using AFVs • Funding to offset transaction fees when using credit cards at AFV stations • Financial grants for training operators and maintainers of AFV stations • Re-visit *fuel-use* incentives such as those used in methanol program • Eliminate federal tax on state incentives	• Expanded HOV access (e.g., for clean-fueled MDVs and HDVs) • Streamlined approval and permitting of AFV stations from code and fire-safety officials • Rideshare or other incentives for employers that install EV chargers • Preferred public parking for SULEV (or better) AFVs • Administrative incentives for installation of AFV stations during new commercial construction • Improve *convenience* of using AFV stations (or, minimize *inconvenience*, which is a disincentive)

6. Appendix A: Air Quality Regulations and Petroleum Displacement

6.1 Light-Duty Vehicles

In California, LDVs have been subject to the world's most stringent emissions standards since the late 1960s. In recent years especially, major strides have been achieved in reducing emissions from conventionally fueled LDVs, directly as a result of the California Air Resources Board's (CARB) landmark Low-Emission Vehicle regulations adopted in 1990, as well as "competition" from low-emitting vehicles deployed under the Energy Commission's Methanol Program. Gasoline-powered Super-Ultra-Low Emission Vehicles (SULEVs), are now available at comparable prices to conventional LDVs (see Table 53). These vehicles emit about 95% less ozone-precursor emissions (reactive hydrocarbons and NOx) compared to vehicles meeting the basic standard. However, one dedicated natural gas vehicle, the Honda Civic GX, was recently certified as California's first Advanced Technology Partial Zero-Emission Vehicle (ATPZEV).

Table 53. 2001 LDV types certified to CARB's most stringent emissions standards

	No. of MY 2001 Passenger Car Engine Families Certified in California to Standard		
Technology Type / Fuel	**ZEV or PZEV***	**SULEV****	**ULEV*****
Internal Combustion Engine / Gasoline	0	2	18
Internal Combustion Engine / Compressed Natural Gas	1 [a]	0	1
Hybrid-Electric / Gasoline	0	2[b]	0
Battery Electric / Grid Electricity	4	0	0
Fuel Cell Electric / Methanol or Hydrogen	0	0	0

Source: CARB website, June 2001. Additional certifications may have occurred that were not yet posted on the website.

*PZEV = Partial Zero-Emission Vehicle, **SULEV = Super-Low Emission Vehicle, ***ULEV = Ultra-Low Emission Vehicle

[a]The CNG-fueled Honda Civic GX was recently designated as an Advanced Technology PZEV

[b]Both commercially available hybrid-electric vehicles – the Toyota Prius and the Honda Insight (CVT version) – are SULEVs and use parallel hybrid configurations (gasoline engine, electric motor / nickel metal hydride battery pack)

With progressively cleaner cars becoming commercially available, operators of LDV fleets can achieve significant emissions reductions in their fleet simply through the practice of replacing older vehicles with gasoline-fueled ULEVs and SULEVs. As long as advanced-technology gasoline LDVs can meet the most stringent standards at little or no incremental vehicle and infrastructure costs – and gasoline remains affordable and abundantly available – air quality may not be a driving force to deploy significant numbers of light-duty AFVs in California over the next five years.[152] However, the use of clean fuels in certain light-duty

[152] Over the longer term, LDVs using clean fuels (e.g., methanol or direct hydrogen) are expected to deliver zero or near-zero emissions while simultaneously displacing large volumes of gasoline fuel.

applications can still offer compelling benefits towards sustainable use of alternative fuels in California, directly resulting in displacement of petroleum fuels.

6.2 Medium-Duty Vehicles

As Table 54 shows, a total of three engine families in the medium-duty sector have been certified to SULEV standards. Two of these engine families, Chrysler's 5.2 liter CNG engine and Ford's 5.4 liter CNG engine, use alternative fuels, while one engine family (Acura 3.5 L MDX) has achieved the SULEV standard with gasoline. SULEVs in this category are 70% lower emitting than average new vehicles of similar weight, according to CARB (details about these categories can be found at CARB's "Buyer's Guide to Cleaner Cars" at http://www.arb.ca.gov/msprog/). To date, eight medium-duty engine families (from several manufacturers) have been certified to the next-cleanest (ULEV) standard for the 2001 model year. These MDVs are 50% cleaner than the average new vehicle of similar weight. The net result is that very low-emitting alternative fuel vehicles are available in medium-duty applications, and their use will result in direct displacement of gasoline consumption. However, their use strictly for air quality benefits may be less compelling, given the improving emissions-competitiveness of gasoline-fueled MDVs.

Table 54. Recent MY medium-duty vehicle certifications by type

	No. of MY 2001 MDV Engine Families Certified in California to Standard		
Technology Type / Fuel	**ZEV***	**SULEV****	**ULEV*****
Internal Combustion Engine / Gasoline	0	1	6
Internal Combustion Engine / Compressed Natural Gas	0	2	1
Hybrid-Electric / Gasoline	0	0	0
Battery Electric / Grid Electricity	4	0	0
Fuel Cell Electric / Methanol or Hydrogen	0	0	0

*ZEV = Zero-Emission Vehicle (2000 Model Year)
**SULEV = Super-Low Emission Vehicle
***ULEV = Ultra-Low Emission Vehicle

6.3 Heavy-Duty Vehicles

In the heavy-duty vehicle (HDV) sector, the use of alternative fuels can displace large volumes of petroleum fuel while also delivering clear and compelling emissions benefits, at least in the near term. There are approximately 350,000 HDVs registered in California for on-road vehicle use.[153] Including out-of-state vehicles, an estimated 550,000 heavy-duty on-road diesel trucks and buses are driven throughout California. Including off-road diesel-fueled HDVs, approximately 1.25 million heavy-duty diesel engines are operated in California.[154] Many of these engines are equipped with little or no emissions control

[153] California Energy Commission, California Energy Outlook 2000: Volume II Transportation Energy Systems, August 2000.

[154] California Air Resources Board, California's Plan to Reduce Diesel Particulate Emissions: Fact Sheet, October 2000.

technology. On-road HDVs alone contribute nearly 40% of all NOx emissions from mobile sources in California. NOx is a major ingredient in the formation of ozone, the main harmful component of urban smog. Fine particulate matter exhaust from heavy-duty diesel engines contributes to mortality, and CARB has identified it as a toxic air contaminant.[155]

Today there are numerous alternative-fuel heavy-duty engines that have demonstrated superior emissions performance compared to currently available diesel engines. As of early 2001, no diesel-fueled engines have been certified to CARB's optional low-NOx standard (2.5 grams per brake horsepower-hour) for HDVs. By contrast, since the 1998 model year more than a dozen heavy-duty natural gas engines meeting these standards have been offered commercially in California.

Largely based on the proven emissions-reduction potential of various alternative fuel HDVs using these engines, California agencies have adopted regulatory drivers and/or incentives to assist deployment of these vehicles. For example, CARB's Public Transit Bus Fleet Rule was specifically designed to increase deployments of low-emission alternative-fuel engines, including advanced battery and fuel cell technology use.[156] About 8,500 transit buses will be affected at 75 different transit districts. As of March 2001, 26 transit districts have chosen the alternative fuels path, 40 have chosen the diesel path, and 9 have not yet declared.[157] For transit agencies that have selected the alternative fuel path, at least 85 percent of all new bus purchases must be alternative fuel through the 2015 model year.[158] Transit agencies that have chosen the "diesel" path must obtain equivalent fleet-averaged emissions reductions by 2010. Included for larger transit districts (>200 buses) is the requirement to conduct demonstrations of Zero-Emission Buses (ZEBs) in 2003 and begin purchasing ZEBs in 2008 -- two years before transit districts on the alternative fuel path.

California's air pollution control districts are also adopting major drivers for HDVs using alternative fuels. The South Coast Air Quality Management District has adopted a series of "fleet rules" for end users in the South Coast Air Basin (SCAB) that effectively require a phasing out of current-technology diesel vehicles in favor or heavy-duty AFVs, or their emissions equivalent. Table 55 lists SCAQMD's adopted or proposed fleet rules affecting HDVs, and the estimated populations for potential conversion to alternative fuels.

[155] California Air Resources Board, "CARB Identifies Diesel Particulate Emissions as a Toxic Air Contaminant," Press Release 98-51, August 27, 1998.

[156] California Air Resources Board, Staff Report: Initial Statement of Reasons – Proposed Regulation for a Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses, January 27, 2000.

[157] Fax from Alvaro Gutierrez, California Air Resources Board, to Jon Leonard on April 10, 2001.

[158] Although transit agencies are not required to purchase alternative fuel buses certified to an optional low-NOx credit standard (2.5 g/bhp-hr NOx or lower), those are the only certified alternative fuel bus engines currently available. In addition, bus engines certified to an optional low-NOx credit standard can qualify for incentive funding.

Table 55. SCAQMD's adopted or proposed fleet rules affecting HDVs

SCAQMD Fleet Rule No.	Targeted Fleet Type(s)	Estimated SCAB HDV Population for Potential Conversion to Alt. Fuels[159]
1192	Transit Buses	5,000
1193	Refuse Haulers	6,000
1194	Airport Support Vehicles	500
1186.1	Street Sweepers	700
1196	Heavy-Duty Public Fleets	4,100
Total		**16,300**

Sources: SCAQMD staff reports on fleet rules, and personal communication from David Coel, SCAQMD, to Jon Leonard, ADLittle on 3/27/01

However, as regulators acknowledge in these rules, the emissions competitiveness of diesel-fueled HDVs will rapidly improve over the next decade. The major drivers are a series of progressively more stringent new heavy-duty engine emission standards, coupled with requirements for cleaner diesel fuel, promulgated by CARB and EPA. In late 2000, CARB approved a comprehensive Diesel Risk Reduction Plan that includes 14 measures to reduce emissions from both new and existing diesel-fueled engines and vehicles. Among these measures are the establishment of more stringent emissions standards that will take effect in 2002 and 2004. In early 2001, EPA also adopted more stringent emissions requirements for heavy-duty diesel engines. As part of this program, new emission standards will take effect in model year 2007 and will apply to HD highway engines and vehicles. To meet these standards with diesel engines, it is expected that manufacturers will need to incorporate advanced diesel emission control technologies such as catalyzed diesel particulate filters and NOx adsorbers. Because sulfur renders these systems ineffective, both CARB and EPA are requiring sulfur levels in highway diesel fuel to be reduced more than 90% by 2006.[160,161]

As a result, there is less certainty about the emissions advantages of alternative fuels after the 2002 low-NOx standards are initiated for heavy-duty engines, and the 2004 NOx standards take full effect. Heavy-duty engine manufacturers have indicated that advanced diesel engine technologies combined with low-sulfur diesel fuel will be able to duplicate or better the emissions performance of today's alternative fuel engines. Meanwhile, several manufacturers are also involved in efforts to further reduce emissions from their natural gas engines, to NOx levels about 75% lower than today's natural gas engines.[162]

[159] These numbers are educated estimates, according to SCAQMD. The actual number and rates of AFVs introduced will be affected by 1) each fleet rule's phase-in rate and exemptions, 2) availability of various AFV types, 3) fleet turnover rates, 4) available funding. On average, full phase-in of these rules is expected to occur between 2010 and 2015.

[160] California Air Resources Board, California's Plan to Reduce Diesel Particulate Emissions: Fact Sheet, October 2000.

[161] U.S. Environmental Protection Agency, Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, December 2000.

[162] Under a program jointly funded by the Energy Commission, the SCAQMD and NREL, two programs are being initiated to develop and certify 0.5 g/bhp-hr NOx HD engines. The engine OEM participants are Cummins (with Westport Innovations) and Detroit Diesel Corporation.

Looking out past 2004, air-quality drivers for alternatively fueled HDVs become even less concrete. By 2007, both diesel and alternative-fuel heavy-duty engines will need to emit about 90% less NOx and PM than today's lowest-emitting alternative fuel engines. These fuel-neutral standards will be challenging for both advanced diesel and alternative fuel engines. However, it is noteworthy that diesel engines have significantly "farther to go" in reaching the target levels. Taking an alternative fuel approach may offer significant engineering and cost advantages, at least for certain engines and applications.

7. Appendix B: Maps and Linkages for AFV Technologies

7.1 Clean Fuel Station Mapping

There are a number of government agencies and private stakeholders that have developed very effective mapping systems for most of California's AFV fueling stations. By far the best available information is focused on "public access" stations. Station operators with large anchor fleets have less need for maps because vehicles are returned to the same fueling base each day. Map systems for public-access stations play an important role in assuring existing and potential AFV users that the vehicle can be driven as needed, without fear of not finding the alternative fuel in the region of travel.

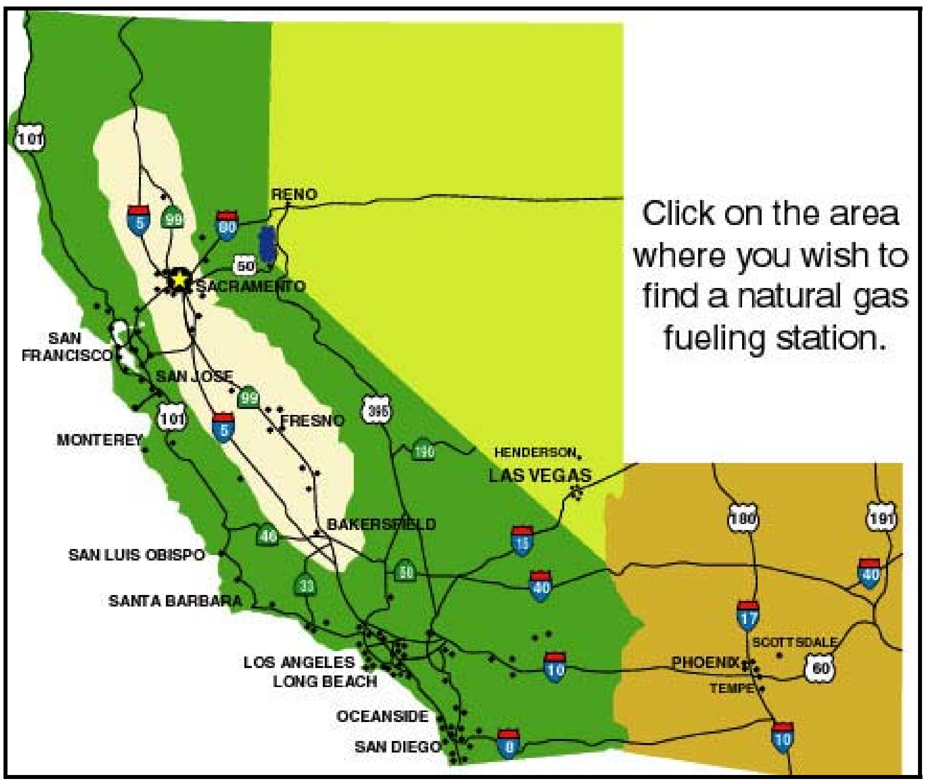
Increasingly, "hard copy" map systems are being replaced by Internet sites, which enable the NGV user to quickly go on line and locate an AFV fueling station in the area where he or she expects to need fuel. Table 56 lists some of the more prominent websites that offer effective web-based mapping systems for alternative fuels such as CNG, LNG, propane, E85, and electric charging.

Table 56. Websites with maps for clean fuel stations

Website Name / Operator	Address	Featured Fuels
California NGV Coalition	http://www.califngv.org	CNG
Calstart / Westart	http://cleancarmaps.com	CNG, LNG, LPG, Methanol, Ethanol, Hydrogen, Electric
DOE / NREL	http://afdcmap.nrel.gov	CNG, LNG, LPG, Methanol, Ethanol, Hydrogen, Electric
Trillium USA	http://www.trilliumusa.com	CNG
ICTC / Gladstein & Associates	http://www.gladstein.org	LNG, L/CNG
Magnecharge	www.magnecharge.com	Electric (using Magnecharge system only)
Pinnacle CNG	http://www.pinnaclecng.com	CNG
Pickens Fuel Corp.	http://www.pickensfuel.com	CNG, LNG, L/CNG
Sacramento Municipal Utility District	http://www.smud.org/evs/	Electric (all charging stations in Sacramento County)
Southern California Edison	http://www.edisoncars.com	Electric (all charging stations in Edison's territory), with sightseeing "itineraries" that are within available driving range of EVs

Figure 7-1 shows the web-based mapping system of the California Natural Gas Vehicle Coalition, which allows the user to click on any region of California to find available natural gas fueling stations. The National Renewable Energy Laboratory's mapping system is one of the most comprehensive for various types of clean fuel stations.

While these mapping systems are very user friendly and convenient, a spot check of each website found that it's very common for the maps to be out of date, or inaccurate. For example, Cleancarmaps.com shows that there are currently 13 M85 stations in California, all of which are operational. This information is out of date, but it's useful that mapping systems are in place for fuels such as methanol, if the methanol-refueling infrastructure re-develops to fuel methanol-reformate fuel cell vehicles. Cleancarmaps.com is also already set up to map hydrogen stations in California. However, it currently shows no existing stations for automotive applications. The hydrogen station at Sunline Transit Agency in the Coachella valley is technically open for business, but its use is currently restricted to special vehicles such as the XCELLSiS fuel cell bus.



Source: http://www.califngv.org/pacificcoastmap.jpg

Figure 7-1. Web-based map system for the California NGV Coalition

7.2 Relationships to Clean Cities

The national Clean Cities program is founded on the use of locally based government/industry partnerships to encourage the use of alternative fuel vehicles and their supporting infrastructure. Public and private AFV stakeholders located throughout northern and southern California have joined into Clean Cities Coalitions, and played an essential role in expanding the number of clean fuel stations. The Department of Energy and the Energy Commission are among the many government agencies that have assisted the Clean Cities program to encourage AFV development, as a means to achieve both energy security and environmental quality goals.

CNG Vehicles and Stations

California's CNG stations have been well integrated into these activities. Table 57 lists some of California's Clean Cities stakeholders and how they have helped to develop, demonstrate, and assess CNG vehicles and the associated fueling infrastructure.

Table 57. Relationship of Clean Cities and California's CNG infrastructure

Clean Cities Stakeholder	Examples of Involvement with CNG Infrastructure
Bay Area AQMD	♦ Use of CNG vehicles and expansion of CNG station network
California Air Resources Board	♦ Use of CNG vehicles and expansion of CNG station network ♦ Promulgation of regulations resulting in expanded NGV use
California Energy Commission	♦ Use of CNG vehicles and expansion of CNG station network
CalStart / WestStart	♦ Cleancarmaps.com mapping of CNG stations ♦ Listing of vendors for CNG fueling stations and NGVs
City of Los Angeles	♦ Use of CNG vehicles and expansion of CNG station network
City of Sacramento	♦ Use of CNG vehicles and expansion of CNG station network
City of Tulare	♦ Use of CNG vehicles and expansion of CNG station network
Coalition for Clean Air	♦ Promotion of heavy-duty CNG vehicles to displace diesel-fueled vehicles
County of Sacramento	♦ Use of CNG vehicles and expansion of CNG station network
FleetStar Incorporated	♦ Provider of CNG fuel at 9 fueling stations
Pacific Gas and Electric Company	♦ Provider of CNG fuel at 35 fueling stations ♦ Promoter of NGVs and infrastructure
Paratransit	♦ Operating CNG buses and fueling station
Pickens Fuel Corporation	♦ Turnkey provider of CNG fueling stations
Sacramento Metro AQMD	♦ Use of CNG vehicles and expansion of CNG station network
San Diego County APCD	♦ Working on AFV Master Plan for San Diego County
San Diego Clean Fuels Coalition	♦ Use of CNG vehicles and expansion of CNG station network
San Joaquin Valley Unified APCD	♦ Use of CNG vehicles and expansion of CNG station network
South Coast AQMD	♦ Use of CNG vehicles and expansion of CNG station network ♦ Promulgation of fleets rules leading to NGV use and new CNG fueling stations
SoCal Gas Company	♦ Use of CNG vehicles and expansion of CNG station network
US Department of Energy	♦ Use of CNG vehicles and expansion of CNG station network ♦ EPACT and other efforts that increase NGV use

LNG Vehicles and Stations

Generally, the focus of the Clean Cities program has been on alternative fuels for light and medium-duty vehicle applications. Since LNG is used primarily for heavy-duty vehicles, to date it has not been a key fuel in the Clean Cities program. However, California's Clean Cities stakeholders tend to have diverse interests (i.e., beyond light-and medium-duty vehicles) that include activities to deploy LNG vehicles and the associated fueling infrastructure. Also, Clean Cities activities to deploy CNG vehicles can be tied to LNG activities, because CNG vehicles can be fueled at L/CNG stations, which are specialized LNG stations that also offer CNG (see section 4.2.3).

Propane Vehicles and LPG Stations

Many of California's Clean Cities help to sponsor development and deployment of LPG-fueled vehicles. LPG suppliers are often involved in their local Clean Cities program, to assist with infrastructure needs and demonstrations of LPG vehicles. Table 58 provides other examples of California's Clean Cities stakeholders involved in activities that directly or indirectly help to expand the use of LPG vehicles in California.

Table 58. Examples of Clean Cities Involvement in Propane Infrastructure

Clean Cities Stakeholder	Examples of Involvement with LPG Vehicles and Infrastructure
California Air Resources Board	♦ Promulgation of regulations that may promote greater deployment of LPG-fueled vehicles
California Energy Commission	♦ Offers infrastructure development activities that can include LPG stations
City of Los Angeles	♦ Use of LPG vehicles including LPG-fueled hybrid with Capstone microturbine auxiliary power units ♦ Current RFP to expand clean fuel infrastructure
Coalition for Clean Air	♦ Promotion of clean fuel HDVs including those powered by LPG
County of Sacramento	♦ Potential deployment of agriculture pumps fueled by LPG
Automakers (Ford, GM)	♦ Production at factory of LPG-fueled engines
Sacramento Metro AQMD	♦ Potential Moyer funding of LPG-fueled agriculture pumps
San Diego County APCD	♦ Working on AFV Master Plan for San Diego County
San Joaquin Valley Unified APCD	♦ Potential Moyer funding of LPG-fueled agriculture pumps
South Coast AQMD	♦ Promulgation of fleet rules that may encourage expanded use of LPG-fueled low-emission vehicles
Ventura County APCD	♦ Potential Moyer Program funding of LPG-fueled agriculture pumps

EVs and Electric Charging Stations

Many of California's Clean Cities help to sponsor development of EV charging stations and expanded use of EVs. Most Clean Cities have at least one public charging station or fleet charging station. Table 59 provides other examples of California's Clean Cities stakeholders involved in activities that directly or indirectly help to expand California's EV charging station infrastructure.

Table 59. Examples of EV infrastructure activities by Clean Cities stakeholders

Clean Cities Stakeholder	Examples of Involvement with EVs and Charging Infrastructure
California Air Resources Board	♦ Promulgation of ZEV regulations that promote infrastructure development
Bay Area AQMD and City / County of San Francisco	♦ Collaborate on EV infrastructure funding program
California Energy Commission	♦ Offers EV infrastructure development activities and charging stations (residential and public)
CalStart / WestStart	♦ Cleancarmaps.com mapping of EV stations ♦ Listing of vendors for EVs and charging stations
Coalition for Clean Air	♦ Promotion of EVs as foundation of California's clean air strategy
County of Sacramento	♦ Use of EVs and expansion of the charging station network
Pacific Gas and Electric Company	♦ Use of EVs and expansion of the charging station network
Automakers (Ford, GM, Honda)	♦ Contribute funding to EV infrastructure development (residential and/or public)
San Joaquin Valley Unified APCD	♦ Funds EV infrastructure development activities
South Coast AQMD	♦ Funds EV infrastructure development activities ♦ Promulgation of fleet rules that encourage EV use
Mobile Source Air Pollution Reduction Review Committee	♦ Completed two large public infrastructure programs to expand EV charging stations in the South Coast region
Ventura County APCD	♦ Funds EV infrastructure development activities

Hydrogen Vehicles and Fueling Stations

California's Clean Cities stakeholders are also helping to directly or indirectly promote hydrogen fuel and fuel cell vehicles. Examples are provided in Table 60 below.

Table 60. Examples of Clean Cities stakeholders involved with hydrogen infrastructure

Clean Cities Stakeholder	Examples of Involvement with Hydrogen Infrastructure
California Air Resources Board	♦ Promulgation of regulations that ultimately promote deployment of direct-hydrogen fuel cell vehicles ♦ Member of California Fuel Cell Partnership ♦ Co-sponsor of hydrogen "Blueprint" plan (see text for description)
California Energy Commission	♦ Member of California Fuel Cell Partnership ♦ Ongoing infrastructure support including hydrogen related ♦ Co-sponsor of hydrogen "Blueprint" plan
Automakers (Ford, GM, many others)	♦ RD&D programs involving direct hydrogen fuel cell vehicles ♦ Member of California Fuel Cell Partnership
South Coast AQMD	♦ Promulgation of fleet rules that may encourage direct-hydrogen fuel cell vehicles ♦ Funding of H2 infrastructure programs (e.g., RFP# P2001-17) ♦ Member of California Fuel Cell Partnership
U.S. Department of Energy / NREL	♦ Ongoing work to develop and deploy hydrogen-fueled vehicles ♦ Co-sponsor of hydrogen "Blueprint" plan
Sunline Transit Agency	♦ Demonstration of two different hydrogen fueling station technologies to fuel California's only fuel cell bus

7.3 Relationships to Interstate Clean Transportation Corridor

As a general rule, the Interstate Clean Transportation Corridor (ICTC) is focused on the deployment of heavy-duty vehicles using LNG or L/CNG. Extensive information can be found about LNG vehicles and fueling stations at the official website of the ICTC (www.gladstein.org). Gladstein & Associates manages the ICTC program and recently performed a survey of LNG fleets using the ICTC. Information from those surveys is incorporated into this report.

Whenever possible, the ICTC project promotes the construction of fueling stations that dispense both these fuels, such as the L/CNG stations currently under development for the cities of Tulare and Barstow. While conventional CNG stations are an integrated part of the corridor concept, and they help increase the density of natural gas stations within the ICTC, deployment of these stations has been spearheaded by other market forces.

Other fuels may have peripheral existing relationships with the ICTC. According to Delta Liquid Energy, there is one automotive LPG station along the ICTC, located on Interstate 5 near Santa Clarita. Two more are planned along the ICTC (I-5 in La Mirada and I-80 in Roseville). In addition, Delta is "researching potential sites with freeway access adjacent to existing propane powered fleets."

Hydrogen vehicles in the next five to ten years are most likely to be used only by transit districts that refuel onsite each night. Therefore, deployment of a hydrogen-fueling infrastructure along the ICTC corridors is not a high priority in the foreseeable future. This could change over the longer term, as direct-hydrogen fuel cell vehicles become available that are conductive to over-the-road use, and assuming the ICTC program is perpetuated.

8. Appendix C: Summary Tables by Fuel Type

8.1 Near-Term Clean Fuel Infrastructure and Vehicles

Table 61. Summarized status of near-term clean fuel infrastructure and vehicles

	Type of Clean Fuel Technology (Vehicle and Infrastructure)					
Parameter / Issue	**CNG**	**LNG**	**L/CNG**	**LPG (automotive)**	**EV Charging**	**E85**
Existing and known planned stations in California	~240 existing unknown planned	~8 existing ~18 planned	~2 existing ~3 planned	~10 existing up to 30 planned	~3,300 existing unknown planned	0 existing unknown planned
Average throughput at public access stations, per month	3,000 to 8,000 GGE[a]	No data	No data	<1000 GGE (but very little for vehicles)	No data	None
Average throughput for HDV fleet and transit applications	10,000 to 25,000 DGE[b]	5,000 to 50,000 DGE	15,000 DGE	No data	No data	None
Existing relative degree of petroleum displacement in 1) Transit Buses 2) HD Trucks, 3) MDVs and LDVs	1) High 2) Moderate 3) Low	1) Moderate 2) Moderate 3) N/A	1) Very Low 2) Very Low 3) Very Low	1) Low 2) Low 3) Moderate	1) Very Low 2) None 3) Very Low	1) None 2) None 3) None
Current fuel price (retail)	~$1.60 per GGE	~$0.55 per LNG gal (untaxed) ~$1.24 per DGE (taxed)	No data	~$1.90 per GGE	$0.04 to $0.12 per kWhr, (depending on time of use and other factors)	$1.40 to $1.60 per E85 gallon (no fuel in California)
Capital cost for average public access station (w/o land)	~$500,000 to $750,000	~$500,000 to $750,000	~$200,000 over LNG station's cost	$35,000 to $100,000	$7,000 to $10,000	No data
Capital cost for large HDV or transit bus station (w/o land)	~$1.7 million or higher	~$1.5 million or higher	~$400,000 over LNG station's cost	~$700,000	N/A	~$400,000 for neat ethanol
Relative operation and maintenance costs for station	Highest	Moderate	Provides CNG at lower O&M costs	Low	Very Low	Low
Commercial availability of vehicles for fuel (low or zero emission certified)	Wide variety of LDVs, MDVs and HDVs	~7 HDV engines	Same as CNG	Some dedicated and bi-fuel LDVs /MDVs, 2-4 dedicated HDV engines	Limited EVs available, primarily in LDV and LDT applications	At least 8 E85 compatible FFVs for 2001 MY
Current incremental cost of clean fuel vehicles	Up to $7,800 (LDVs/MDVs), up to $50,000 for HDVs	Up to $40,000 for most HDVs	Same as CNG	~$5,000 for LDVs and MDVs, higher for HDVs	Up to $20,000 Manufacturing Cost, Up to $10,000 consumer least cost	No incremental cost (standard equipment on many LDV models)

[a]Gasoline Gallon Equivalent
[b]Diesel Gallon Equivalent

Table 62. Estimated potentials and recommendations for near-term clean fuel infrastructure and vehicles

	Type of Clean Fuel Technology (Vehicle and Infrastructure)					
Parameter / Issue	**CNG**	**LNG**	**L/CNG**	**LPG**	**EV Charging**	**E85**
Estimated timeframe for full (self sustained) commercialization	0 to 5 years	O to 10 years	0 to 10 years	1 to 1.5 years (for automotive use	5 to 10 years	Unknown
Anticipated relative growth of vehicle / fuel type by 2005	Low to Moderate	High (> 40%)	Linked to CNG vehicle supply and LNG stations	Low to Moderate	Low to Moderate	None to Low (specifically, for fuel use)
Estimated vehicle population using fuel in California by 2005	~5,000	~3,000	(Unknown fraction of CNG vehicle population)	Unknown – depends on bi-fuel and dedicated products	5,000 to 15,000	0 (1000s of FFVs, but not using E85)
Estimated potential to displace petroleum fuels by 2005 in 1) Transit Buses 2) HD Trucks, 3) MDVs and LDVs	1) Medium 2) Low 3) Medium	1) High 2) High 3) Very Low	1) Low 2) Low 3) Medium	1) Low 2) Low to Medium 3) Medium	1) Very Low 2) Very Low 3) Low to Medium	1) Very Low 2) Very Low 3) Very Low
Estimated # of stations needed in California to achieve full commercial status	2000 to 3000	Estimates vary; survey input: ~20 to 30; LNG market plan: 30 to 40	No data (linked to CNG vehicle supply and LNG station growth)	Unknown – depends on vehicle deployments. LPG vendor: at least 30	No data, depends on vehicle deployments	FFVs already commercialized; no data or input on station development
Estimated minimum monthly fuel use to justify new stations	~15,000 GGE	~15,000 DGE	No data (see above)	~10,000 GGE	No data	No data
Examples of major barriers to expanding the infrastructure **(in addition to California's current energy crisis, which affects virtually all fuels)**	-Station capital, O&M costs -Vehicle cost -Fuel quality -Lack of common card readers	-Station capital, O&M costs -Vehicle cost -Long lead time to purchase vehicles -Fuel tank costs	-Station cost -Lack of lubricity -Lack of knowledge by end users about options	-Lack of dedicated OEM vehicles -Vehicle cost (especially HDVs) -Permitting / code issues	-Cost of EVs (battery packs) - Lack of standard for common charger	-Fuel cost -Lack of fuel-use requirements for FFVs -Competing demand as an oxygenate
Recommended relative priority for infrastructure funding	Medium	High	Linked to LNG	Medium	Needs further study	Very Low
Recommended vehicle applications / activities for highest priority funding allocations or further study	High fuel-use MDV fleets (e.g., taxis); school buses	Waste haulers, transit buses, Class 8 trucks	Complement of MDVs and LDVs at LNG sites	High fuel-use MDVs w/ dedicated engines or bi-fuel pickups (if fuel-use guaranteed)	Perform assessments to determine market and extent of funding needed (if any)	None
Potential sources of cost sharing for infrastructure development	GTI-IWG, fuel providers, APCDs, Moyer Program, MSRC	GTI-IWG, fuel providers, APCDs, Moyer Program, MSRC	GTI-IWG, fuel providers, APCDs, Moyer Program, MSRC	Clean Fuel USA, Caltrans, APCDs, Moyer Program, MSRC, OEMs	Utilities, EV producers/ auto OEMs, APCDs, MSRC	No input received

8.2 Longer-Term Clean Fuel Infrastructure and Vehicles

Table 63. Summarized status and recommendations for longer-term clean fuel infrastructure and vehicles

	Type of Clean Fuel Technology (Vehicle and Infrastructure)	
Parameter / Issue	**Neat Methanol**	**Hydrogen**
Existing fueling stations in California	Approximately 10	A few demonstration stations exist for vehicle fueling
Anticipated timeframe for early-deployment vehicles	2002	2001 (1 to 2 buses)
Anticipated timeframe for commercial vehicles	2004 to 2006	2008-2010 (transit buses only, limited #s)
Estimated potential to displace petroleum fuels by 2010 in 1) Transit Buses, 2) HD Trucks, 3) MDVs and LDVs	1) Low 2) Very Low 3) Very Low	1) Low 2) Very Low 3) Very Low
Estimated number of stations in California needed to support vehicle demand, 2005-2010	Too many unknowns; Methanex Corporation estimate: up to 1,000	~5 for transit applications, others unknown
Estimated fuel price compared to gasoline or diesel, 2005 timeframe (equivalent energy basis)	Equivalent or moderately higher	Higher to much higher (2 to 4 times is often cited)
Recommended action under Clean Fuels Infrastructure Development Plan	Track progress and provide ongoing updates in subsequent Assessments before allocating funds	Track progress and provide ongoing updates in subsequent Assessments before allocating funds
Applications for highest priority	Passenger cars, transit buses	Transit buses
Potential sources to carry early cost sharing for infrastructure development	DOE, SCAQMD, Fuel Cell Partnership, Georgetown University , vehicle and engine manufacturers, fuel cell manufacturers, methanol producers and trade associations	DOE, SCAQMD, Fuel Cell Partnership, vehicle and engine manufacturers, fuel cell manufacturers, hydrogen producers and trade associations